A FRAMEWORK FOR IMPLEMENTING A CSCW ENVIRONMENT TO IMPROVE PRODUCT DEVELOPMENT DECISION-MAKING

by

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DEDICATION

To my parents - whose love and support made me who I am.

To my wife Brooke - my partner, my love, and best friend.

To my son Michael - the joy of my life.

ACKNOWLEDGEMENTS

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LIST OF ACRONYMS

AAR	After Action Review
ACE	Advanced Collaborative Environment
ACT	Advanced Concepts Team
ACTD	Advanced Concept Technology Demonstration
ANOVA	Analysis of Variance
BPM	Business Process Management
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off The Shelf
CSCW	Computer Supported Cooperative Work
DMS	Document Management System
DoD	Department of Defense
DSM	Design Structure Matrix
FEA	Finite Element Analysis
FMEA	Failure Mode and Effects Analysis
FTTS	Future Tactical Truck System
GSS	Group Support Systems
GUI	Graphical User Interface
HEMTT	Heavy Expanded Mobility Tactical Truck
IPDD	Integrated Product Design and Development
IT	Information Technology

JSP	Javascript Page
MCDM	Multiple Criteria Decision Making
MHC	Material Handling Crane
MHE	Material Handling Equipment
MSV	Maneuver Sustainment Vehicle
NATO	North Atlantic Treaty Organization
NDR	Need-Decision-Result Relationship
NPD	New Product Development
NPVR	Net Present Value Risk Adjusted
OSI	Open System Interconnection
PDD	Product Design and Development
PLM	Product Lifecycle Management
PLS	Palletized Load System
R&D	Research and Development
SLOP	Strategically Limited Obsolete Perishable
SMART	Simulation and Modeling for Acquisition, Requirements, and Training
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
TACOM	Tank-automotive Armaments Command
TARDEC	Tank-Automotive Research, Development, and Engineering Center
TMJ	Temporo-mandibular joint pain
UML	Unified Modeling Language
XML	Extensible Markup Language

CHAPTER 1 - INTRODUCTION

The goal of this research is to propose a framework for enhancing the use of Computer Supported Cooperative Work (CSCW) based tools and other enabling technologies to improve decision-making processes in a product development environment. Specifically, the framework has been targeted for application to decisions typically made in the "concept development" phase of product development.

The framework research focuses in two core areas – *implementation* of CSCW and related system tools supporting the product development process and *usage* of fielded systems in product development activities. Some of the key areas addressed within the framework are summarized below.

- Implementation of a hierarchically-based CSCW architecture for managing all data and aspects of the concept development process.
- Leverage the use of past decision data within concept development activities.
- Organization of data elements baselined around a robust product development process.

This report describes in detail the core elements that contribute the framework as well as a prototype architecture developed to support the research.

Findings from a field study, where the prototype architecture was applied to a concept development problem, will also be presented.

MOTIVATION

The motivation of this research is by optimizing the *entire* process of deploying and applying computer tools targeted at product development purposes, a more robust information set can be presented to an end user to contribute to reducing elements of uncertainty inherent with concept development decision making activities.

PROBLEM DESCRIPTION

Throughout all product development activities, decision making remains a cornerstone activity affecting virtually every aspect of the process. The challenge of any product development organization is to ensure consistent, timely, and complete information is provided to decision makers to allow for faster, more accurate and overall improved decision making. Within product development, decisions are typically made by individuals or groups functioning in areas of design, engineering, production, or finance [1].

Bringing new products to market is a relentless task due to competitive and technological pressure being exerted from outside organization boundaries as well as constraints on time and other resources originating from within an organization. Despite research and advances put forth through formalized product development processes, CSCW tools, and other technologies, the process of bringing a product from concept to market has not become any less complex. While few organizations can fully influence all variables affecting product development, many are attempting to identify ways to maximize resources, in part through better decision making.

Problems attributed to product development decision making are nowhere more relevant than in the concept development phase as referred to by Ulrich and Eppinger [2], where many key decisions influencing the direction and outcome of the product are made. Unfortunately, this is also a time where information related to the product development cycle is at its most nebulous,

especially in the case of new product development. Consider the following examples where decisions made during product development resulted in adverse situations:

- An electronic equipment manufacturer was hit hard when a competitor introduced a group of products incorporating newer digital technology. The newer technology enabled components to operate as part of an integrated system networked with other equipment. Although the manufacturer's management was not ignorant of the capabilities of advanced digital technologies, it was blind-sided by the competitor because it had not realized the importance of making a decision about whether or not to incorporate newer digital technology into its products. [3]

- In the 1990's, Vitek, Inc. was a Houston-based manufacturer of medical products, including a jaw implant for TMJ (temporo-mandibular joint pain) patients characterized as chronic pain sufferers. Oral surgeons implanted the devices in approximately 30,000 patients. Of this patient base, about 500 filed product liability lawsuits over a five-year period, alleging a number of problems with the implants. Though many oral surgeons backed the product and a high percentage of patients have reportedly been helped, the crescendo of litigation hounded Vitek into Chapter 7

bankruptcy and a U.S. Food and Drug Administration mandated recall of the Vitek TMJ. [4]

- A major electronics company identified an exciting new market opportunity and launched a team to develop the product. Soon after the project started, focus began to drift. Several important design alternatives were identified, but a decision was needed to select a concept to move forward. Several months passed without a final decision. Because a decision could not be made regarding the initial functionality of the first product release in a timely manner, product entry was delayed by several months. By the time the product was released, delays in decision-making proved to be devastating as a competitor beat the company to market.[3]

These three cases illustrate examples where poor choices made within the development cycle resulted in substantial downstream product issues. While the qualifiable issues within these products came down to factors related of timing, quality, or market acceptance, a root cause issue among all three cases can be attributed to how decisions were made against levels of uncertainty. In all cases, decision makers could have benefited from additional information that may have influenced the outcomes in different ways.

As previously mentioned, information used for decision making during concept development is typically at its most nebulous, especially in the case of new product development. Decisions made during concept development contain

some level of uncertainty which can be attributed, in part, to sources identified below:

- Overall Market Conditions – Although product creators attempt to "simulate" future customer's wants and needs [5] through analysis and forecasting [2], factors such as economic conditions, environmental conditions [5], competitors, or other social events may adversely affect the acceptance of the product in the marketplace.

- Technological Changes – Fast-evolving advances in technology may render a new product obsolete upon introduction. Product developers are constantly challenged with trying to design products with a goal in mind that neither makes it technologically obsolete nor dependent on an emerging technology that is too new for practical application. [6]

- Human Aspect – "To Err Is Human" [7]. Decision makers are human and are fallible to unknowns. Decisions are typically based on an analysis of information available on the problem as well as personal perceptions, preferences, and knowledge that is gained from experience. Unfortunately, knowledge and perspective that one decision maker may have does not readily transfer to other decision makers. Workers change jobs frequently, and rarely is

knowledge retained at a level to allow for replacements to fully understand complex decision environments.

With a hypothesis that uncertainty (as related to any number of factors) affects concept development, some improvements in overall development cycles can be attributed to the evolution and expansion of computer tools allowing information to be managed and/or processed in new ways. Toyota's world class product development system is based on a balance of streamlined processes and technology working to create a lean environment [8]. Computer technologies such as CSCW and the Internet have transformed how organizations collaborate by linking cross-functional, distributed teams with a common information base. General Motors is an example of a product development organization now producing cars developed collaboratively over multiple continents [9].

However, despite improvements brought forth by the use of collaborative computer technologies, uncertainty in decision making remains a concern to product developers. In some cases, computer systems deployed to improve information processing in product life cycles failed to deliver intended benefit [10] [11], including situations where the collaborative information system has become little more than an electronic replacement to paper-based file systems – a "collector" of legacy data subsequently not utilized in a manner which could influence organizational development cycles [12].

RESEARCH QUESTION

Despite tremendous resources spent on deploying computer systems to provide users access to a comprehensive information set, the activity of decision making for product concept development remains an effort rife with complexity and risk. Simply put, *what can be done to optimize development-focused computer tools to allow improvement by reducing levels of uncertainty in concept development based decision-making?*

OBJECTIVES

In many ways, the basis for addressing the research question translates into an optimization process for based on two principles:

- *Locating the "right" information needed to make decisions.* The inability to locate information in organizational computer systems can be time consuming and costly. In some cases, decision makers feel they do not have access crucial information they should have – and know exists – due to limitations with existing computer tools and supporting processes [13] In other cases, decision makers use free form searches in an attempt to discovered information they *think* may exist which could support their needs – "if we only knew what we know" [13].

- *Retaining and transforming information for future decision-making.* The practice of capturing lessons learned – knowledge intended to help educate and aid in making future decisions – is usually best formalized either in "project notebooks" or after action reviews. While lessons learned information is captured in computer systems, it is typically not stored or linked in a manner allowing it to be readily applied to future decision making activities. Therefore, a goal will be to transform "static" information such as decision

history and concept artifacts into "dynamic" data sets that can be leveraged by decision makers.

With this context in mind, the two main research objectives can be succinctly stated.

1. *To put forward an approach for creating and utilizing a CSCW architecture with the aim of reducing decision uncertainty in the concept phase of product development activities.*

2. *To describe how data points harvested from past decisions can contribute toward and impact future concept development decision making activities.*

EXPECTED CONTRIBUTIONS

Identification of a series of steps covering both implementation and usage for optimizing a CSCW system to benefits decision makers.

As mentioned, the focus of the framework includes elements for application toward implementation ("pre-production") *and* usage ("production"). Many system optimization approaches focus on an "either... or" strategy. While each element within the framework can be leveraged in a "stand along" context, the combination of the elements together is intended to have a greater aggregate effect on a CSCW system designed to support concept development activities than if applied individually. Finally, the framework is constructed to be robust enough for continued application as computer technology evolves.

Introduction of the "Need-Decision-Result" (NDR) relationship for extracting, storing, and reusing decision-related data

While some key decision details are encompassed within the "lessons learned" realm of archived information, the use of "purely historical" decision data has not traditionally been positioned as a valued commodity for aiding future product development decision making. In some applications, decision information becomes a checkpoint event with output relegated to indefinite storage with no further purpose then to serve an occasional audit or report. By capturing key elements of a decision having relevance to future decision makers, combined with narrative information supporting both "before" (the needs) and

"after" (the results) aspects of the decision, decision makers can benefit from a tangentially unique data set.

CHAPTER 2 – BACKGROUND

This chapter describes the results of an information search conducted to understand key foundational concepts from the general body knowledge preceding this research effort. The emphasis on the search was to locate appropriate literature that meets one or more of the following criteria:

- Contributes relevant ideas supporting the context of the research.
- Takes an applied, practical approach to the subject matter rather than purely theoretical approach.
- Describes case studies or examples related to applicable development practices leveraging collaborative technologies.

The nature of the research draws from several well-documented technologies, including product development processes, CSCW systems (including workflow-based processing and system integration), decision making, content search and filtering techniques, and risk assessment. Although many of these topics have been well-researched through the years, substantial opportunity exists to contribute new ideas to the literature as the momentum of technology advance drives the evolution of these foundational concepts.

PRODUCT DEVELOPMENT PROCESSES

Product development processes are a set of steps and phases describing a standard means by which a company repetitively converts embryonic ideas into salable products or services [14]. The study of product development processes has generated substantial interest as a research subject for academia and a strategic asset for companies engaged in delivering products to consumers. Globalized marketplaces, combined with the rapid evolution of the modern information age (in particular, the rise of the World Wide Web) has created the most challenging environment for product development in history [15].

Over the past decade, several important methodologies detailing the functions involved with developing products have been put forth [2][5][16]. While each methodology approaches the product development process somewhat uniquely, all share important elements:

- The need for an integrated, cross-functional team working collaboratively to share information [16].
- The ability for a product development team to draw upon organizational core competencies to help create new products [17].
- An infrastructure supporting team collaboration across barriers of time, distance, and cultural differences [16].
- An organization flexible enough to adapt to changing conditions and circumstances [18].

One of the more influential and comprehensive product development process frameworks has been developed by Karl Ulrich and Steven Eppinger. The process, formally called the Product Design and Development (PDD) process, divides the numerous activities of product creation into six major phases – planning, concept development, system-level design, detailed design, testing and refinement, and production ramp-up [2]. A summary of the PDD process is provided in Table 2.1.

Phase	Title	Description	Activities
Phase 0	Planning	"Pre-Project" activities laying groundwork for project	- Technology review - Marketing Objectives - Project Mission Statement
Phase 1	Concept Development	Concepts selected for further development and testing	- Marketing targets - Concept Descriptions
Phase 2	System-Level Design	Definition of Product Architecture	- Decomposition of Product into Subsystems and Components - Functional Specifications
Phase 3	Detail Design	Complete Specification of Product	- Detailed Geometry and Specifications - Material Identification - Tooling Designs - Controlled Documentation
Phase 4	Testing and Refinement	Construction and Evaluation of Pre-Production Versions	- Alpha and Beta Prototypes - Reliability Testing - Design Changes
Phase 5	Production Ramp-Up	Final Release and Production of Product	- Workforce Training - Pilot Production Runs

Table 2.1 Major Phases of the PDD

Within the PDD, phases are linked to one another as outcomes from one activity become inputs to others. A representation of the entire PDD model is provided in Figure 2.1 [2].
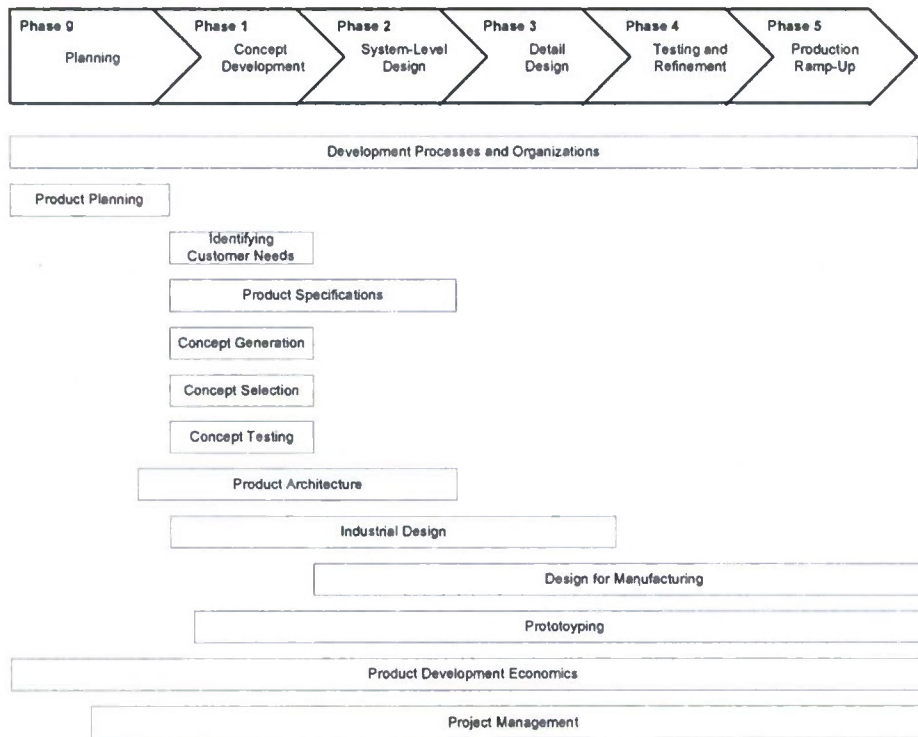
Figure 2.1 The Product Design and Development Process

Although each phase of the PDD represents an important step in the formation of a product, it is within the "Concept Development" phase where a great deal of momentum for research interest is focused [5]. It is in the concept development phase where many critical decisions affecting the entire development spectrum are made as raw ideas are translated into product

concepts. These activities and critical decisions made "up front" are referred to as being at the top of the "product development funnel" [16].

Within the Ulrich and Eppinger model, the concept development phase contains six activities where the target market is defined, alternative product concepts are generated and evaluated, and one or more concepts are selected for further development. The six activities of the concept development phase are summarized below.

- *Identifying Customer Needs:* Understand the needs of the customer and communicate to development teams.
- *Establishing Target Specifications:* Translation of customer needs into technical terms representing "goals" of the development team.
- *Concept Generation:* Explore the space of product concepts to satisfy customer needs.
- *Concept Selection:* Analysis of product concepts leading to the identification of an optimal (or promising) concept.
- *Concept Testing:* Activities to determine if customer needs have been met and assess the market potential of the product
- *Setting Final Specifications:* Commitment to specific values and metrics.

Input to these activities includes product planning, economic analysis, benchmarking, modeling, and prototyping. Information used for decision-making

in the concept development phase of the PDD is generated through contributions from a multidisciplinary team representing all major functions in the organization, including marketing, design, and manufacturing. Standard information types provided by contributors include customer data, market intelligence, design data, and preliminary engineering analysis [2]. Additionally, mapping product planning attributes to manage product portfolios can help decision makers understand the implications of product development decisions [19].

What separates Ulrich and Eppinger's Product Design and Development process from others is the depth of detail provided from cross-functional participation, which lends itself for the broad, managed inputs which are important to this research framework. In particular, information in the front-end phases used to drive decisions and activities is at its most nebulous, or "fuzzy" [18] [20], due in part to uncertainties that have been attributed to future market conditions [21], technological advances and shrinking product life cycles [6], or other factors that may be related to organizational or environmental changes. Therefore, the goal of the early phases of product development is to emerge with a solid, comprehensive product concept [1] based on the information produced by the cross-functional product team.

Of relevance to this research is literature related to product development aimed at process description or problem solving techniques. Iansiti et. al. [15] described a "flexible", concurrent approach to product development citing software development projects as "primary advocates" of the process. Stein et. al. [16] provided a good summary of product development activities similar to the

Ulrich and Eppinger process and introduced the term "product development funnel" as applied to early concept generation and planning. Recent literature focuses on better decision-making in the early phases of New Product Development (NPD). Herrmann et .al. [1] described the product development in terms of decisions rather than phases. Tsinopoulos et. al. [22] expanded on the role of decision-making in product development by advocating a three-stage approach. Jetter [5] proposed use of Kosko's Fuzzy Cognitive Maps (FCM) approach linking requirements, technologies, and components to help in developing product concepts.

In recent years, a great deal of interest on product development activities has been focused on the Japanese automaker Toyota. Long cited as the leader of PDD in automotive practices, the Toyota product development system represents the best example of the incorporation of "lean development". The concept of "lean" reached prominence in the 1990's with Womack et. al. [23] description of the Toyota development environment which focused on "first-time" quality, waste minimization, continuous improvement, flexibility, and long-term supplier relationships. One of the first detailed analysis of the Toyota product development environment was provided by Morgan [24], which was later enhanced by Morgan and Liker [8]. Kennedy also provided substantial context on the application of the Toyota system into a typical US-based automotive environment [25].

In 1999, Monplaisir [26] proposed an Integrated Product Design and Development (IPDD) CSCW architecture based on using online decision-making

tools, collaboration workgroups, and Web-based processing. Incorporating earlier research by Monplaisir, Riordan, and Benjamin [27], where the use of CSCW architectures was applied to agile cell manufacturing, the IPPD was targeted directly at the concept and design phases of product development. In 2002, using the IPDD as a foundation, Monplaisir focused on the impact of decision-making by introducing the Multiple Criteria Decision Making (MCDM) model [28]. The MCDM employs a clustered neural network model to aggregate preferences and reduce the complexity of decisions in a CSCW environment. Using ANOVA validation, the MCDM showed statistically significant difference in time required for decision-making in relation to overall quality of work.

Several practical problem solving techniques for product development were identified in the literature. Sosa et. al. [29], Eppinger et. al. [30], and Huang [31] all described product development in terms of a flexible, modular product architecture. Nepal et. al. [32] described a framework for multi-objective optimization of product architecture. A closely related approach generally applied to product development in order to group dependencies and map sequences is the Design Structure Matrix (DSM) [33]. Whitney et. al. [34], Dong et. al [35], Salhieh [36], and Yassine et. al. [37] [38] each provided detailed examples of DSM in product development activities.

COMPUTER SUPPORTED COOPERATIVE WORK (CSCW)

First coined in the 1980's [39], Computer Supported Cooperative Work (CSCW) systems have emerged as a key component supporting business activities. The roots of CSCW can be traced decades earlier when, in 1945, Vannevar Bush called on scientists to consider how to make the accumulating body of human knowledge more accessible to people while offering the first glimpses how "machines" can be used for storing and sharing information [40]. CSCW tools provide a technological solution for organizations to base distributed information sharing, retention, and process functions. Greif (1988) included applications supporting CAD/CAM, office systems, joint authorship tools, and project management in the general definition of CSCW [41]. A reason for the continued success of CSCW tools is the ability to offer true collaboration across the time and space continuum.

As described by Monplaisir [28], successful CSCW systems encompass the following characteristics:

- Interaction capability in either synchronous or asynchronous mode.
- Coordination of tasks to be performed by members of a team.
- Distribution capabilities to enable interaction from remote locations.
- Accessibility and sharing of data among participants.

Information on CSCW-based processing is prevalent in the literature, with numerous journals and books dedicated to the subject. Many of the contributions discuss the technical nature of CSCW systems as opposed to descriptions of applied, integrated systems – of which the latter is more relevant to this research. Even in cases where the focus of the work was targeted toward applied systems, many contributions have been rendered technologically obsolete due to the advent of Web-based architectures. A relevant example describing applied CSCW systems was Munkvold [42], who provided case studies on the use of collaborative technologies within large companies like Boeing, Grudin [32], and Andriessen [44], who described the types of variables that can affect CSCW systems.

Romano, Nunamaker et. al. [45] described the use of an integrated information retrieval system in conjunction with Group Support Systems (GSS). Romano's premise is based on users ultimately end up searching for information to support decision activities, and a linked information retrieval system will benefit the overall decision-making process. In almost a 'premonition' to this research, Romano opens his work with the following statement – "it is surprising to the authors that very little attention has been given to the common ground shared by these two important research domains..." [45]. Although the need for information filtering was mentioned as a way to eliminate redundant data, Romano does not offer details on how such a system could be implemented. Further, the authors did not consider how large information sets (potentially

returned from an integrated search) can possibly blur relevance between relevant and useless information items.

For a solid theoretical overview, Borghoff and Schlichter [46] offer a wide perspective on the use of CSCW with an important discussion on workflow processing. Karsten et. al. [47] describes the impact of collaborative technologies by categorizing the usage and impact of the tools on various organizations with an innovative "before and after" approach. In terms of using CSCW tools as a central component to product development, Mills [33] offers a comprehensive look at CSCW and Web-based tools that are linked to product development, and Monplaisir and Singh [48] tie together several important topics related to product development problems, including Monplaisir's review of CSCW fundamentals and Riordan's discussion of decision-making and Groupware (where the elements of CSCW-based decision-making are presented). Bochenek et. al. [49] [132] describes the use of collaborative environments combined with virtual reality tools to support design reviews. CSCW and virtual product design has also been described by Steward et. al. [50] and Kubo et. al. [51]. Other good references where CSCW tools have been used support group work efforts include Patel et. al. [52] and Newman et. al. [53].

Benyon-Davies et. al. [54] describes the use of conceptual modeling related to linking database schemas into a collective, "collaborative" system. The process by which the schemas are linked through attribute relationships at the sub-system and system level influences data management for this research. Benyon-Davies also proposes CSCW architectures as an ideal framework on

which to develop "collaborative" database schemas. Dewan [55] proposes the use of functional decomposition of collaborative systems into smaller subsystems, whereby various models and requirements can be developed. The premise of the modeling activity is to develop an architecture that offers complete collaborative capabilities.

CSCW WORKFLOW MANAGEMENT SYSTEMS

Task coordination is a central component in CSCW applications. Workflow systems are technologies supporting the automation of work activities by routing information among different participants according to a predefined sequence [42]. In most cases, workflow processes are implemented after a rigorous information-gathering activity including identification of requirements, development of functional and data flows, and process mapping. More specifically, workflows represent the operational aspect of a work procedure - how tasks are structured, performed (and in which order), level of syncronization, information flows to support the tasks, and how the overall process is being tracked usually through the measure of processing rates (as a dimension of time) and overall throughput [67]. Workflow processes typically embody a formalization of work activities that represent organizational "best practices" in order to drive improvement through repetition.

In general, workflow management systems have been well-documented in the literature, including several complete texts dedicated to the subject by Khoshafian et. al. [56] and Jablonski et. al. [57]. Borghoff et. al. [46] provides an excellent theoretical overview of workflow processing and definition. Numerous accounts of successful application of workflow systems can be found in the literature, including Ben-Shaul et. al. [58], Trung et. al. [59], Muth et. al. [60], and Adkinson et. al [61], where described improvements include improved status

tracking, consistency and conformity to work standards, improved productivity, and improved management support through balanced task allocation.

Morschheuser et. al. [62] provides a good non-Web based algorithm for locating pertinent documents using workflow processing. Of particular interest is the opening statement – "…information which is embedded in paper documents is partially or entirely lost after their active processing has terminated…" - which is an influence on this research (making use of decision information). Cho et. al. [63] uses a model-based approach for linking metadata from CAD systems and plant floor systems within a workflow application to support traditional back-end processing activities. McClatchey et. al. [63] applies workflow systems to product development using several examples, and Kang et. al. [66] describes the use of a secure workflow system as the core for distributed task management in a DoD environment for passing sensitive information between domains. Munkvold [42] lists workflow integration with legacy applications as an important implementation factor for "coordination" of technologies.

While an important element in business process optimization, some documented examples describe less-than-optimal workflow system implementations. Weske et. al. [64] and Bowers et. al. [65] detail problems including a lack of detailed planning and prototyping in the workflow development process, inadequate translation of the business process into workflow activities, and system performance issues.

An important aspect related to the research is the use of workflow applications to link CSCW and organizational data sources. To improve internal

work processes or leverage information for competitive advantages [68], many organizations are attempting link business systems to provide a fluid movement of various types of data throughout the enterprise. Liang et. al. [69], Chang et. al. [70] and Simone et. al. [71] propose a CSCW architecture that includes considerations for using data sources from other business applications. Reinhard et. al. [72] describes the taxonomy of a CSCW architecture with "collaboration transparent" applications.

From a perspective of technology choices for workflow-based applications, Schmidt [73] offers an overview of evolving workflow technologies, while Wade et. al. [74] and Delic et. al. [75] each propose using a CORBA-based architecture. Du et. al. [76] uses a distributed model for allocating resources within the workflow process and offers a useful layered model (similar to the OSI model) for accessing resources. Ganesarajah et. al. [77] use a "SOAP-over-HTTP" architecture for integrating workflow systems, thus providing a way to incorporate Internet-based sources.

From a design and construction perspective, Hawryszkiewycz [78] describes a design methodology centering on CSCW and Heinl et. al. provides guidelines for flexible design practices in workflow systems [93]. Contributions supporting XML modeling within CSCW-based applications include Marsic et. al. [79] and Ma [80]. Literature aimed at XML-based transactions within workflow processes includes Yang et. al. [81], Lear et. al. [82], and Kanaya et. al. [83]. Aversano et. al. [84] proposes using XML as a medium for distributed document management and workflow processing and recommends the UML for core data

modeling. Later, Aversano et. al. [85] uses UML-based modeling – in particular activity diagrams and use cases – to develop workflows for a variety of systems. Finally, Agostini et. al. [86] offers a short specification for complex workflow modeling through decomposition and development of "simple" workflow models.

CONTENT RETRIEVAL TECHNOLOGIES

Among the most important tools developed for Web-based processing are those designed to conduct searches based on one or more keywords. Although the search and return sequence is a near-seamless transaction to the end user, these actions are typically the result of complex data gathering and sorting activities. Given the importance of Web searches to Internet use, search tools have essentially become the "card catalog" system of the Internet [87].

Search engines use a variety of mechanisms (including human interpretation) [88] to continually identify and categorize new information from the Web. After classification, search engines employ a series of conditional probability techniques to sort and rank data. Many of the leading search technologies use Bayesian principles to synthesize representations of conditional probabilities [89] or filter information based on key attributes [90]. Gupta et. al. [88] proposes a search engine architecture to allow "fresher" information and data to be brought forward more easily within Web searches. Henzinger et. al. [91] describes a search engine ranking algorithm based on the comparison of a number of similar parameters, and Hou et. al. [92] expands on the comparison techniques by adding additional components into the search algorithm. Beyond text-based searches, Funkhouser et. al. [94] developed query heuristics based on orientations and design similarities to search within 3D models and drawings. Linden et. al. [90], uses content filtering agents to extract a very small subset of personalized recommendations from an extremely broad data pool. Linden's

model represents a real-world application of item filtering and selection (Amazon.com).

DECISION UNCERTAINTY

Decision analysis is a discipline comprised of theories, methodologies, and practices necessary to address making important choices in a formalized manner – particularly in situations having levels of uncertainty [95]. The rich history of contributions in the area of decision analysis includes Clemen [96], Raffia [97], Howard et. al. [98], and Skinner [99], among others. Branches of decision analysis are rooted in Operations Research practices [100], DSM, and software system design [101]. Pablo et. al. [114] ties concepts of decision making as being central to understanding risk, and Richardson et. al [115] frames decision making within a decentralized environment, concluding organizational characteristics play a larger role in decision making performance than other factors.

Two areas of interest within decision analysis play an integral role in the formulation of the framework. The first area is role of bias as it affects uncertainty in decision making. According to the Prospect Theory developed by Amos Tversky and Daniel Kahneman, decision makers evaluate gains and losses to assess decision alternatives based on personal bias [102]. Evaluations of alternatives are based on a reference point where decisions gravitate toward. According to Tversky and Kahneman, several important heuristics and biases come into play during decision making:

- Representativeness – Judgments of probability are based on what is perceived as similar to a belief or known quantity.

- <u>Availability</u> – Concentrating primarily on evidence that is easily obtained or immediately available.

- <u>Anchoring</u> – Concentrating on evidence or facts that are presented first in the overall set.

Mellers et. al [116] follows Tversky's work with studies on how emotion, beliefs, and "rule following" also contribute to the psychological makeup of the decision maker.

The second area of interest is the assessment of risk and the role risk plays in decision-making. Risk, in its basic definition, is the potential harm that may arise from some present process or from some future event [103]. The realm of risk-related topics and research is extensive as related to product development. Smith et. al provides a detailed, multi-step approach to monitoring and managing risk in new product development [104]. Davis leverages the use of "net present value, risk adjusted" (NPVR) to evaluate relative risk in product development projects [105]. Thornton focuses on variation quality as related to Six Sigma practices [106]. Kraniak et. al. shows how historical data for product development as related to manufacturing planning can be effective for use in Failure Mode and Effects Analysis (FMEA) data [107].

A common method of risk assessment is to arrive at an optimal decision through decision trees. Decision trees are used to arrange outcomes of decision in a series of nodes with associated risk probabilities and costs called branches [100] [108]. Decision trees are typically leveraged in two ways – traditional

optimization problems involving the application of possible outcomes combined with a calculated probability [109] or a classification structure to based on training data within the realm of artificial intelligence-based learning [110].

LITERATURE GAPS

As stated in the introduction to this chapter, foundations of the core research can be considered "ground well covered". However, important gaps in the literature have been identified.

- The need for a comprehensive, focused approach for optimizing CSCW environments for product development activities during planning, implementation, and production. While several works mention using CSCW within the mechanics of product development decision making at a high level, the framework offers practical optimization steps for both implementers and users. In contrast, none of the reviewed works provide more than rudimentary discussions with functional or technical detail.

- The research provides a path for the use of past decisions and relevant historical data points for decision makers. While Romano and Nunamaker [45] make reference to decision data as one point of information, no literature goes into sufficient detail on harnessing concept-based decisions for future usage.

CHAPTER 3 - METHODOLOGY

As presented in Chapter 1, the premise of the framework is based on the research question - *What can be done to optimizing the current spectrum of development-focused computer tools to allow improvement by reducing levels of uncertainty in concept development based decision-making?* In Chapter 2, core fundamentals on which the framework has been based were presented, including an explanation of the concept development (and product development) phases as well as applicable computer technologies, theories, and processes.

The purpose of this chapter is to provide in-depth information related to the framework by defining its major elements, implementation strategies and associated methods. To understand how the research can contribute to improving concept development processes, an investigation was undertaken which provided indicators that allowed the core framework elements to be identified. The bulk of this chapter is devoted to an in-depth explanation of the research framework elements.

SURVEY OF PRODUCT DEVELOPMENT ORGANIZATIONS

A starting point for understanding how the framework can impact concept development was to gather a small sampling of feedback on how organizations approach product development. The data gathering approach consisted of identifying individuals from a variety of product development communities and extracting a baseline of experiences through a review of concept development activities.

Members of the product development communities contributing to the data gathering activities ranged from small companies to multinational corporations in the automotive, software, and defense areas. Individuals involved with product development activities were directly queried regarding their processes, information systems, and issues with moving concepts forward. The feedback was collected by utilizing live interviews and a written questionnaire (which can be found in Appendix A).

Product Development Processes and Tools

- Most respondents utilize some level of product development processes involving computer-based information systems. Typically, the larger the organization (and "deeper the pockets" for investing in tools), the higher the degree of automation tools for concept development, data management, and collaboration (such as workflow systems). Further, many of the organizations rely on

internally-developed processes synthesized over time from successful practices.

- Typically, computer-based tools are either custom applications developed internally or commercial applications tailored to the needs of the organization's product development activities. While custom applications may provide a better fit into an organization's existing product development activities, substantial resources are needed to maintain the systems. Conversely, while commercial applications may not require the same level of dedicated resources for maintenance, commercial applications offer an approach to working with data that can be substantially different to what an organization practices. In many cases, commercial applications are customized to work within the parameters of existing product development practices. Unfortunately, highly customized commercial systems typically have many of the same maintenance issues as "in-house" developed applications.

- At the "low" end, smaller organizations do not typically use sophisticated data management and automation tools but rather rely on rudimentary computer tools (such as a shared disk drives) for managing information. In some cases, teams rely on managing portions of data and processes on external or customer systems. Interaction and data exchange between multiple disciplines on concept decisions (e.g. engineering, manufacturing, design,

financial) continues to be influenced in part by existing personal relationships between participants.

- In some cases, computer systems deployed to support and streamline product development and decision-making activities fall short of their intended goals. In hindsight, some of the shortfalls can be traced to the implementation issues – lack of information used for planning, deployment, adoption, and sustainment.

Data Usage, Lessons Learned, and Decision Making

- The ability to locate information in organizational computer systems can be challenging. In some cases, decision makers feel they do not have access crucial information they should have – and know exists – because of the existing computer tools and supporting processes. In other cases, decision makers use free form searches in an attempt to discovered information that they think may exist which could support their needs – "if we only knew what we know" [13].

- The practice of capturing lessons learned – knowledge intended to help educate and aid in making future decisions – is usually formalized through "project notebooks" or post-mortem activities such as an After Action Reviews (AAR). While lessons learned information through these methods can be captured in computer systems, it is typically not stored or linked in a manner allowing it to

be readily applied to future decision making activities. Most respondents would welcome better ways for capturing and sharing both formal and tacit knowledge relative to decision making.

- The inability to locate and leverage information from organizational computer systems for decision making activities is a byproduct of how the system was implemented and how it is maintained. The sheer physical bulk of information that large enterprise information systems manage can extend well into terabytes. Even those respondents without the resources to implement formal CSCW systems (and thus use rudimentary tools such "shared disk drives" for cooperative data management) mentioned issues with retrieval and reuse. Without an adequate data management strategy, locating information can become an overwhelming chore. Further, the associated time required to do an extensive data search by a decision maker may quickly exceed the overall need to use the information in a decision making activity.

- Decisions are typically based on an analysis of information available on the problem as well as personal perceptions, preferences, and knowledge (best supported by Tversky et. al [102]). Unfortunately, the knowledge and perspective of one decision maker does not readily transfer to another. Workers change jobs frequently, and typically knowledge is not retained to a level allowing for replacements to quickly understand the decision

environment. While some generic lessons learned may be recorded, rarely does transferable "insight" to why a decision was made – which could help a future decision maker faced with similar circumstances – get captured.

- Data derived from past decisions useful for future decision making is related to cost, deliverables, or timing. All other decision circumstances, in general, have little value outside of the particular, point decision.

- The "need" – as reflected through the original concept and subsequent requirements – should ultimately the standard by which the decision should be measured. If a decision has measurable impact on the original "need" as related to cost, deliverables, or timing, then it becomes a candidate for information.

Analysis and Framework Summary

Taking into account the literature review and survey it is clear opportunities exist to improve systems used to facilitate concept development processes. Clarifying the targets of the research, the concentration will be on methods that can provide a measure of impact in the following three areas:

- Improving lessons learned and organizational knowledge.
- Locating and managing conceptual product development information.

- Improving decision-making in concept development activities.

The remainder of the research describes a framework by which actions can be taken to make improvements in the aforementioned areas. The framework is composed of four core elements (briefly summarized below) with a goal presenting a rich, succinct data set to decision makers to allow for additional information to be utilized in the decision making process.

1. *Implement a hierarchically-based CSCW architecture for managing all data and aspects of the concept development process*
   a. Follow a structured implementation process
   b. The CSCW architecture must have the ability to foster process management
   c. Constructed with philosophy of most data captured has little future use with decision makers.
   d. Utilize a series of "measurement" attributes to assess the value of data for future decision making tasks

2. *Leverage the use of past decision data within work processes*
   a. Creation of a decision-focused mechanism allowing appropriate data to be captured at a level that supersedes traditional data management objects.

    b. Creation of the "Need-Decision-Result" relationship linking needs to actions and outcomes

    c. Utilize a criteria based on three core factors – cost, timing, and deliverables – combined with traditional metadata to identify relevant decisions.

3. Organization of data elements baselined around a robust product development process.

4. Integrate risk assessment providing awareness to specific data points that could have relevance to a decision.

The four steps cover both implementation and usage of an environment suited for a concept development decision-making environment. While each element can be implemented independently and outside of the context of the framework, it should be noted the intent is for the elements to be used together to create a synergy for optimization beyond what is attainable if employed separately.

ELEMENT 1 - IMPLEMENT A HIERARCHICALLY-BASED CSCW ARCHITECTURE FOR MANAGING ALL ASPECTS OF THE CONCEPT DEVELOPMENT PROCESS

The cornerstone of the framework is the creation of an environment from which data can be captured, managed, and leveraged for an organization. The purpose of this section is to clarify the components and structure of the essential CSCW elements critical as a foundation for other portions of the.

Core CSCW Architecture Elements

The essential components required for a CSCW system to support a product development framework are summarized below. Because many of these features can be found in commercially-available software products, CSCW system implementers should strongly consider advantages of starting from Commercial "Off-the-Shelf" Technology (COTS) over creating custom applications from scratch.

Object-Oriented Behaviors Data structures supported in the CSCW environment should be based on an object-oriented, expandable hierarchy with persisted objects representing data and actions. Objects should be able to be linked through a variety of explicit relationships. The ability to 'manage' perstistable data objects should be based on pre-defined behavioral characteristics as well as a user- specified data hierarchy (based on locations,

user roles, and other explicitly defined conditions). Each data entity managed within the CSCW environment typically contains two core features – content such as an electronic file (e.g., Microsoft Word documents, CAD file) and context in the form of field-based metadata that describes the associated content and other information used to describe the entity. More importantly, data objects defined in the system should cover all types of information used or stored throughout the life cycle of the product – from concept "bubble-up" to planned-manufacturing obsolescence.

Relational Database Repository. CSCW data elements should be managed within a relational database repository. Most commercial CSCW systems rely on a relational database such as Oracle, Microsoft SQL Server, or MySQL to manage the physical warehousing of data elements.

Context Search and Retrieval. The system must have the ability to support queries for searching database tables and related repositories.

Process Standardization Tools

The system must provide mechanisms to support formalized work processes involving a series of defined events. In many cases, CSCW environments and other systems use workflow-based objects and applications to formalize activities by routing tasks to pre-defined users (or roles) for completion of a specific action. In some tasks, workflow objects capture decision data to record an action on a particular item. Most workflow processes are designed

primarily to standardize and streamline work activities by ensuring the appropriate tasks, roles, and users are identified.

Typically accompanying structured workflows are life cycle phases which represent the maturity of a data element in the development cycle. Together, workflows (as the specific tasks to be completed) and lifecycles (representing the maturity of the data item) represent an approach known as the "phase-gate" (or "stage-gate") process [113]. Life cycle phase data can be a useful element for filtering past decision data.

Controlled Data Hierarchy – Detailed Planning and "Matrixed" Information Approach

System implementers must make understanding *how to structure* the product information ultimately managed within the system a priority. Implementers must understand and gauge four key characteristics of information *before* it becomes managed within the CSCW environment:

- How data is created (by users or automated processes)
- Where data will be structurally stored within the environment
- What information regarding the managed data is important to end users
- How data elements will be related to one another.

In many cases, CSCW system deployments focus more on the "act" of implementing the tools rather than understanding the mechanics of the data to be managed in the system. In some situations, this lack of consideration for long-term data usage results in a "scattershot" approach to data management – multiple data hierarchies with a localized data management approach, thus creating "information silos".

In any data managed environment, a hierarchy of information will evolve in one manner or the other as a result of planning or forecasting – or the lack of it. Without a defined data hierarchy implemented at the time of system deployment, additional context and knowledge obtained from implementing the framework elements will likely be less effective since an underlying principle in the application of the framework is the ability to closely link a variety of information sources related to before, during, and after a decision has been made.

As mentioned, "scattershot" data hierarchies are sometimes a byproduct of how system implementation projects are conducted. In some cases, resources from outside the end user organization (IT consultants) are brought in to deploy the CSCW system with project schedules emphasizing deployment milestones and financial targets. General requirements and organizational data flows are gathered through interviews and studies, but depending on the focus provided by the project team these efforts may not result in an *intrinsic* understanding of how data is captured and leveraged by end users. Conversely, end users and customers, not versed in deploying CSCW technologies, usually

do not have enough understanding of the "to be" environment to be able to fully consider all aspects of data use. The result is a good technological solution without a solid data hierarchy and plan where the end user is left to decide the 'fate' of the data within the system.

In unregulated situations, users have the ability to store information in virtually any accessible location. If data management standards are not established or are misunderstood, a data hierarchy based on local (or individual) standards will grow with few opportunities to link information data elements beyond its singular context. More importantly, opportunities to "discover" information are reduced due to inconsistent data management approaches. Figure 3.1 provides a representation of a localized, or "scattershot" data hierarchy.
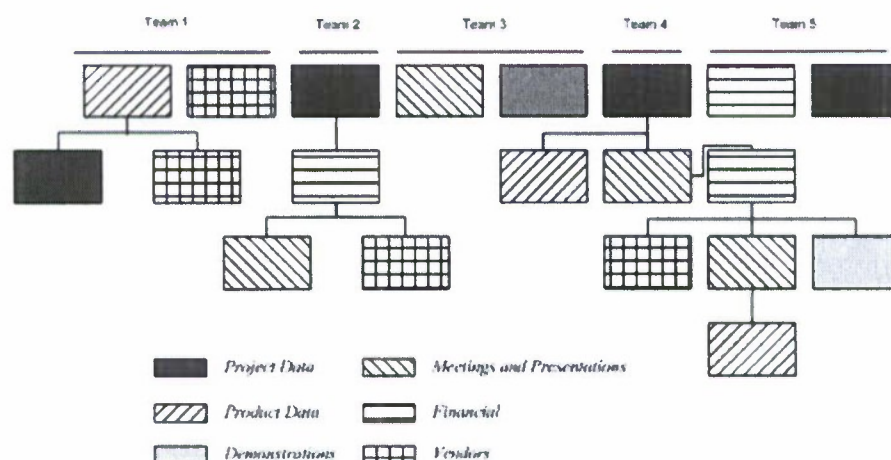

Figure 3.1 Localized ("Scattershot") Data Hierarchy

When considering how to forecast a hierarchical-based data environment optimized for an organization, one recommendation is to identify the information flow that works best from both an end user perspective and a data relationship perspective. An approach for consideration is to construct a "matrixed" view of data for the CSCW environment. Loshin [111] mentions a matrixed perspective for data validation during system development. In a matrixed view, major data categories are identified based on forecasting necessary data types. Data categories referring to a specific entity (e.g. leveraging basic "noun" principles of "person", "place", or "thing") could be considered one type of category. Examples would include references to concepts or physical end products. Conversely, data categories that represent "descriptive" applications of data are another category. Specific data types such as program plans, requirements, and studies represent subjective characteristics. In the matrixed hierarchy, the intersection of specific entity and descriptive data elements (e.g. "the project plan for a concept program") provides a location where the data element should reside in the hierarchy.

Figure 3.2 shows a representative data matrix of information based on entity and descriptive elements. Entities are shown along the horizontal axis (programs and products) and descriptive identifiers are arranged along the vertical axis (demonstrations, meetings, and vendors). Although not shown, within major categories a number of sub-categories may exist.

	Project A Data	Project B Data	Product B Data
Demonstrations	Data Entity	Data Entity	Data Entity
Meetings	Data Entity	Data Entity	Data Entity
Financials	Data Entity	Data Entity	Data Entity
Presentations	Data Entity	Data Entity	Data Entity
Vendor Information	Data Entity	Data Entity	Data Entity

Figure 3.2 Matrixed Data Hierarchy

Because only a subset of data has value to future decision makers, the matrixed hierarchy promotes an efficient data management arrangement by keeping the most important data elements at the highest level. The matrixed hierarchy also provides a starting point for locating information, thus reducing the chance of creating independent information "silos".

One caveat is since most computerized environments are most efficient in managing data in a singular hierarchy (or "top-down" one-dimensional approach), for implementation purposes it may be necessary to transpose the matrix where one type of category (entities) are placed in a superior hierarchical position with the support of the other category. An example of a transposed data matrix is provided in Figure 3.3.

```
Project A Data              Project B Data              Product B Data
    |                           |                           |
    ├─ Demonstrations           ├─ Demonstrations           ├─ Demonstrations
    ├─ Meetings                 ├─ Meetings                 ├─ Meetings
    ├─ Financials               ├─ Financials               ├─ Financials
    ├─ Presentations            ├─ Presentations            ├─ Presentations
    └─ Vendor Information       └─ Vendor Information       └─ Vendor Information
```

Figure 3.3 Transposed Data Matrix Hierarchy

Dynamic Data Management

Although large amounts of data can be stored indefinitely in computer managed environments, only as subset of the information has value beyond its originally intended use.   Problems resulting from massive data build-up are mentioned in the survey – in particular, difficulty searching and locating information.

CSCW data environments working within the research framework should be construct and operated with a dynamic philosophy that most of the data captured has little future use with decision makers. For a healthy environment supporting decision-making, system designers must capitalize on a perishable quality of data recognizing a finite lifespan of usefulness. Extending a concept from Tversky [102], decision makers may be biased by the first sources of information in hand. Therefore, an operating principle within the framework is *data not having usefulness should be pre-filtered out of any potential list of information a decision maker accesses in order to gather inputs*.

Indicators in the form of attributes are needed to identify concept data (i.e. deliverables, not specifically decision data itself) having relevance for future use.

There are obvious 'natural' indicators captured as part of the metadata itself – primarily the age of the data item, life cycle state, or specific relationship to an important concept. For data not as obviously perishable, straightforward criteria should be deployed as part of the managed attribute set to allow data creators an opportunity to provide a measure of assessment. To facilitate a simple recommendation process, assessment-based attribute data should be Boolean information ala check box, radio button, or true/false. How data may be relevant to future decision makers is not important since filtering information for later use will be a feature of other components in the framework as well as be a weighting factor for search engines. However, having this "pre-determination" up front helps separate potentially relevant data from other information having no further use.

In general cases, the following information elements may be used as part of the decision assessment criteria - *decision, issue, end state, timeframe, milestone, resource, or requirement.* Conversely, data items not falling within the pre-defined criteria well eventually become data *SLOP* (Strategically Limited, Obsolete, Perishable). SLOP items should be automatically archived or deleted after a pre-determined time. Where possible, data SLOP items should have minimal weighting in search engine indexing (or a "negative" weighting over time).

ELEMENT 2 - LEVERAGE THE USE OF PAST DECISION DATA WITHIN WORK PROCESSES

According to Ulrich and Eppinger, it is in the concept development phase where the needs of the target market are identified, alternative product concepts are generated, and concepts are selected for further development and testing [2]. To translate requirements (in terms of wants and needs) into workable concepts, numerous activities and decisions must be completed during the process. Ultimately, decision results from concepts influence activities far beyond the concept development phase.

Decision makers interpret alternatives, assess information, and make comparisons in order to develop a conclusion. As discussed in Chapter 2 within the context of Tversky's heuristics and biases [102], decision makers draw insight from data in hand and personal experience. The value decision makers bring to this process is their ability to make complex rationalizations from a limited information set. As evident from the literature and survey, improvements are welcome for capturing organizational memory beyond traditional "lessons learned".

Gaining context how decisions have been made or, more importantly, played out over time becomes an intriguing component for leaders. While the decision itself may have some use as a precedence (most prominently in design, where concepts of design intent and design rationale are used to designers), it is how previous decisions were arrived at – in particular what were the key motivating factors - and the "before" and "after" view of the sequence of decision

events which may be of more interest. Therefore, harnessing data from the decision making mechanics becomes an asset for sharing with other leaders in the organization. It is within this context a core element of the framework – the mechanisms to capture and leverage information from past decisions – is presented.

Within the framework, three important structural components must be added to take advantage of decision data:

1. Development of a decision-focused object allowing related decision data to be captured at a level that supersedes traditional CSCW objects.

2. Creation of the "Needs-Decision-Result" relationship linking "before" and "after" data elements to the decision.

3. Utilization of a criteria based on three core factors – cost, timing, and deliverables – combined with traditional metadata to identify relevant decisions.

Creation of a Decision-Focused Object

As previously mentioned, a data model used by many CSCW systems is based on a hierarchy of objects. Objects are used to represent tangible, "real" data elements containing metadata and physical content in some state of development. Typical object hierarchies may include objects representing parts, products, documents, requirements, drawings, or change-related items. All

objects are usually descendents from a simple object defining a basic set of properties or behaviors. Another class of objects describes actions taken on core objects, such as workflow data.

Within the use of "core" and "support" objects to represent decision information, some gaps may exist in the hierarchy to enable management of detailed decision context for capture or reuse [112]. In these cases, the only consistent placeholder for decision data is workflow tasks. In this context, workflows become essentially "one-dimensional" tools not extendable beyond basic task management activities. A task is provided to a decision maker through the CSCW-based application with links to data for which a decision must be made. Decision outcome are registered within the CSCW system for the data item with some additional generic comments from the decision. Once the decision is made, results and comments are recorded and the task is considered finished, left to become part of the vast archive of information. Other than reporting purposes, the workflow decision activity (and data) has no further value. Decisions, for all practical purposes, become byproducts of a series of activities undertaken to achieve a series of stated purposes. In CSCW systems used for product development, the end product becomes the focus of attention (both present and future), not key decisions.

In the framework context, decisions should be elevated to a level in the object hierarchy equivalent or superior to core objects and data. The objective is to place the decision as a stand-alone entity with linkages to data or processes that have influenced (or been influenced by) the decision. Therefore, a new

object (henceforth referred to as the decision object) should be developed for use by the CSCW environment to focus solely on the capture and reuse of decision data. From a hierarchy perspective, the decision object becomes a key collection points for concept information. Much of the metadata information representing the decision object will be similar to standard content objects (with fields such as "Product", "Program", "Name", "Date"). Although each core data object offers relationships to other data elements, the decision object provides a comprehensive view of related information. For this reason, the decision object must have the ability to be searchable and have a relatively simple access point for acquiring information.

Another important consideration relevant to the functionality of the object is in practice, any "major" decision concept is the result or aggregate of a number of smaller and less encompassing decisions. Therefore, from a design perspective, no structural distinction between major and minor decisions will be made, but the ability to denote a "major" decision (e.g. 'importance') will be added to the schema.

In previous sections, reference has been made to capturing and leveraging past decision data with a premise of the act of the decision itself may offer very little value to decision makers. Rather, it is circumstances before and after coupled with the decision - if captured, stored, and presented in a useful manner – that offers a potential windfall of information. The decision object has been offered as a container to explicitly map information related to the decision.

The Need-Decision-Result Relationship

A decision represents a point in time separating two succinct phases - data leading up to a decision being made and data used after the decision. Assume there are data points representing the primary motivators as to why a decision was rendered. These primary items describe the *need*. Events and actions captured farther out over time after a decision collectively represent the *result*. Therefore, the three elements related to each other in the same stream can be aggregated as the Need-Decision-Result relationship, or NDR. The NDR relationship represents traceable linkages to relate the three data types in a manner describing the circumstances of the decision over time.

To further refine the three elements (need, decision, result), the following inferences will be made to the NDR.

- The need is represented in the data hierarchy as a singular item. Each 'need' can be represented by one data item – a statement, recognized deficiency, question, or hypothesis. Simply stated, the need is the starting point from which the NDR can be established.

- Decisions made to take an action on a need may be represented by 1 to n data items. Each decision data point represents a point in time. Multiple decisions related to a need may not occur at the same instance

- Results occurring over time as related to a decision outcome may be represented by 1 to n items. Result may be considered positive or negative data items as identified over a period of time.

The concept of the NDR is predicated on the ability to capture and make use of static, incremental information in a dynamic environment such as decision making. In the sequence of elements beginning with a need and ending with potentially multiple outcomes, a common occurrence is how decision makers handle changing needs over time. The need which triggered one or more decisions and results may have evolved due to modified conditions or other circumstances. Therefore, for the framework to sufficiently support changing conditions, an assumption must be made in the relationship among the need, the decisions, and results where the need itself remains constant throughout the relationship. As constraints and other decisions impact the concept processes, events must be evaluated with respect to the original "need" from which subsequent actions have been taken. Questions to be addressed include how associated decisions are reactive to a new event (such as an engineering change notices placed against a design) impact the original need). If the need itself changes significantly, a new NDR linkage is required since the previous relationship links are not longer relevant to the current process. Within the new stream, many of the individual elements (such as some of the decisions) may be similar enough (or even duplicate) where the overall impact is possibly negligible However, for purposes of extracting context to determine the impact of shifting needs, the NDR streams should be treated independently.

Key Decision Attributes – Cost, Timing, and Deliverables

An important consideration in making decision data applicable for future needs is determining what information should be collected. Harvested decision data should be in a form which can be easily leveraged by future decision makers. Early determinations of what may be relatively useful must start at the time the decision is being made and captured. Information to be added to the decision context includes determining what were important decision considerations, what information made one alternative better than another, and identification of the risks that mattered at the time of the decision?

Additionally, harvesting information not typically included or easily extracted in the decision making process is a challenging and complex problem. Issues include how some decision makers cannot (or will not) devote time to document their thinking and rationale properly, the concern of overburdening decision makers with information capture to the point where the activity becomes burdensome and resisted, and focus on collecting information having no future value in decision making activities.

Therefore, a set of common criteria must be established for both the decision maker and future benefactors of the decision information. Ideally, the person making the decision would know best how to evaluate the decision against the criteria. Because few (if any) decisions are identical, future benefactors would need the same criteria to locate past information that may have relevance to their decision making tasks.

The criteria itself is made up of three core elements – *cost*, *timing* and *deliverable*. Costs are related to financial indicators, including decisions impacts on target goals or changes from original intentions. Timing is related to completion of an item with relation to a schedule of events. Deliverables are expected or realized outcomes from a process activity. Data should be evaluated with an eye towards how the criteria influenced decisions.

There are sound reasons for employing a selective approach to harvesting decision information. First, it is exceedingly difficult to capture within computer tools meaningful input on the individual tradeoffs and thought processes a decision maker goes through. In terms of rationalization, the human mind far exceeds technology in its ability to make multi-faceted, non-linear decisions [117]. Unfortunately, technology limitations – specifically the time required to capture content – makes it virtually impossible to sufficiently detail decision elements in a form to allow extraction for future use. Therefore, attempting to define a highly granular level of information beyond the basic costs, timings, and deliverables is not realistically possible. At an aggregate level, an avenue for identifying trends from bulk decision data would be through data mining. Data mining is the extraction of hidden information from databases [118].

Second, "too much" data can have an adverse affect on both usage and the ability to leveraging past decision data. Decision makers faced with reviewing a very large set of information may overlook important items pertaining to the decision. Overwhelming a decision maker with vast amounts of decision

data (even filtered) can cause an effect generally referred to as the "law of diminishing returns" [117].

ELEMENT 3 - ORGANIZATION OF DATA ELEMENTS BASELINED AROUND A ROBUST PRODUCT DEVELOPMENT PROCESS

When considering the use of applied computer applications to improve product development, organizations should baseline on generic processes proven successful and add process elements which are fundamentally unique to the business. As observed in the survey results, organizations involved with concept development have some levels of processing involving computer-based information systems. While some organizations use 'reengineering' efforts in conjunction with system deployments, others choose to essentially encode existing processes into computer systems which may limit effectiveness of the collaborative technology. Therefore, using a CSCW implementation period to introduce well-accepted processes into an organization is a way to improved efficiency.

As previously mentioned, an influential product development framework has been published by Karl Ulrich and Steven Eppinger [2]. The process, formally called the *Product Design and Development* (PDD) process, divides the numerous activities of product creation into six major phases. Although each phase represents an important step in the formation of a product, it is the amount of guidance provided in the "up front" concept development phase that makes the PDD an ideal candidate as the starting point for standardizing on a product development methodology. Information used for decision making in the concept development phase of the PDD is supplied by a multidisciplinary team

representing all major functions of an organization, including marketing, design, and manufacturing.

The Ulrich and Eppinger concept development phase specifies seven core activities - Identifying customer needs, establishing target specifications, concept generation, concept selection, concept testing, final specifications, and product planning Taken in whole, the purpose for the concept development phase is to oversee the translation of initial requirements and specifications into concepts [2].

From the perspective of the framework methodology, the use of standardized processes provides further support for filtering past data and decisions to bring the most relevant information forward. Similar to the cost, timing, and deliverable criteria previous introduced, using standardized processes allows data to be consistently applied for multiple concepting scenarios.

Introducing change to existing product practices requires acknowledging that short term difficulties may occur. Although an organization's management team may support leveraging standardized processes as agents of change, it is up to project-level personnel to ensure successful application.   Therefore, focusing appropriate resources and energies toward end user adoption is needed to allow the CSCW system to become an agent for change for the organization.

ELEMENT 4 - INTEGRATE RISK ASSESSMENT PROVIDING AWARENESS TO SPECIFIC DATA POINTS THAT COULD HAVE RELEVANCE TO A DECISION

The final recommendation in the framework is to integrate risk tools directly into the decision data sources. Risk, in its basic definition, is the potential harm arising from an unknown future event [103]. As discussed in Chapter 2, the realm of risk-related topics and research is extensive. In order to narrow the scope of risk topics into a tangible element of the framework, the sources and applications of risk will be constrained to items in the space managed within the CSCW environment.

The range of risk-related tools and applications is widespread in theory and practice. Numerous contributors have documented successful applications of risk tools to many areas of product development, including cost estimating, timing, production planning, and alternative selection [107].

The goal is to provide a general awareness for potential risk items based on the identification of specific data points at the same time as NDR data is presented to the decision maker. In this manner, direct correlation can be drawn between decisions and mitigating factors which may require additional consideration. Additionally, a complete review of how past concepts and decisions have faired against known risks over time may be accessible.

Within this element, the same filtering guidelines called out elsewhere to identify relevant artifacts and past decisions can be used to filter risk items

related to cost, timing, and deliverables. Additionally, other criteria (recalls, warranty costs, etc.) can be applied to extract relevant risk information.

CHAPTER 4 - APPLICATION

With the framework defined, the four elements were being applied to a suitable reference target to gauge overall effectiveness of the methodology. In this chapter, identification of a research target and the process of developing a CSCW-based prototype environment leveraging the principles of the framework will be described. The results of using the prototype in two case studies will be presented in the next chapter.

RESEARCH TARGET– U.S. ARMY ADVANCED CONCEPTS TEAM AND THE FUTURE TACTICAL TRUCK SYSTEM (FTTS)

The Advanced Concepts Team (ACT) is an organization within the United States Army Tank-Automotive Research, Development, and Engineering Center (TARDEC), whose mission is to field technologies to will sustain the Army as the world's premier land-based military force. TARDEC responds rapidly to changing battlefield parameters by integrating, maturing and demonstrating emerging technologies [119].

Located in Warren, Michigan, the Advanced Concepts Team is housed on the grounds of the U.S. Army Tank-automotive and Armaments Command (TACOM). TACOM is a major research, development, and sustainment organizations for land-based vehicle systems [120]. TACOM has a rich history as a key developer and manufacturer of tanks and ground vehicles since World War II, including the M1 family of tanks [121].

The role of the Advanced Concepts Team (ACT) is to work with military organizations to develop viable concepts from defined requirements. The ACT team is made up of engineers and scientists having over 500 years of combined experience, allowing decision makers to draw knowledge and insight directly from the team [122]. Typically, the ACT develops a variety of studies and concept designs incorporating physical characteristics into concepts using feature-based requirements. The ACT concept products are in the form of digital mockups, animated models, desktop solid models, simulations, and documents

providing levels of performance prediction indication in the areas of weight, cost, survivability, vulnerability, mobility, transportability, lethality, power, and overall performance [123].

ACT Concept Development Process

The concept development process employed by the Advanced Concepts Team (ACT) has many similarities to the generic process described by Ulrich and Eppinger [2]. Based on interviews and reviews of documentation, the core elements of the ACT concept development process can be summarized below.

1. A request is made from an Army program to engage the ACT in a concept activity. In some cases, the concept work is related to an entirely new class of vehicle, while in other cases it is modification or variation of an existing program.

2. A joint investigation and requirements analysis is conducted for the concept involving the program customer and the ACT.

3. Leveraging existing information from internal databases, initial concepts and technology surveys are generated.

4. A Quality Function Deployment analysis is conducted on the concept information to identify control areas, overall targets, and risk areas.

5. Through an iterative process, development of an initial concept design with a series of target metrics is developed. The customer

provides feedback on concept areas viewed favorably (or unfavorably). In some cases, additional or modified requirements are extracted from the sessions.

6. A series of specific, detailed concepts based on initial concept targets and designs are development by the ACT.

7. The concepts are reviewed by the customer during a formal concept design review. Concepts that are approved move forward for further detailed analysis to include areas such as operational modeling, mobility modeling, and cost analysis.

8. The approved concept and supporting information is released as an Advanced Concept Technology Demonstration (ACTD),

The ACTD typically results in the development of a fully functional prototype to demonstrate the production feasibility of the concept. The outcomes from the ACTD may include an approval to field the technology, a decision to terminate the program, or a decision to move forward with elements of existing technology in conjunction with (or in place of) the demonstrated prototype [124].

Future Tactical Truck Systems (FTTS)

The ACT has been working for on a major land vehicle development program known publicly as the Future Tactical Truck System (FTTS). The goal of the FTTS program is to develop a series of "sustainment" vehicles to support

all types of engagements conducted in a modern military theater. FTTS vehicles are intended to address shortfalls exhibited by the existing fleet of military transports due to an outdated architecture requiring multiple variants, a cumbersome logistics footprint, poor C-130 deployability, poor fuel economy, mobility limitations, and incompatibility with newer Army technology systems [125].

The FTTS program has concentrated on creating only two core "variants" for the program:

- A "Utility Vehicle" designed for a payload of up to 3 tons under a basic 4x4 wheel operation. Variants falling within this vehicle class include light armor command and control vehicles, general utility trucks, and ambulances. [125]

- A larger, delivery-based transport known as the Maneuver Sustainment Vehicle (MSV) with a payload capacity of 13 tons to streamline distribution of cargo, equipment, and personnel. [125]

The Maneuver Sustainment Vehicle (MSV) provides a number of important technological advances aimed to reduce maintenance, provide more features and capabilities, and deliver payload elements without the need for specialized or external material handling equipment (MHE) [125]. Key FTTS vehicle technology advances include:

- Increased fuel efficiency with extended delivery ranges of 600 to 900 miles

- 100% communication support to improve supply delivery accuracy and eliminate unnecessary re-supply activities.

- Intelligent load handling systems.

- Capable of transporting equipment, NATO flat racks, varied mission supplies (fuel. water, ammunition, and other cargo) and standardized containers

Research Applications

Through analysis of the processes and activities undertaken by the Advanced Concepts Team, two opportunities emerged for application of the framework leveraging the FTTS MSV concept. The first opportunity involved the recreation of a design review undertaken during the FTTS MSV concepting phase. The second opportunity was based on studying a new concept component designed specifically for the FTTS MSV, a multi-purpose crane.

The first opportunity represented a broader application of the framework methodology, while the second opportunity was much more focused but touched more elements of the framework. While both opportunities are related to the FTTS MSV, each is distinct enough to be handled with separate treatments.

The approach taken to describe how the framework was applied will be to first provide an overview of the opportunities with focus on the specific areas of interest. The remainder of the discussion will describe the elements of a

prototype developed to support the research opportunities. Results and analysis of the treatments will be provided in subsequent chapters.

Study I: Concept Design Review

One of the milestone events during FTTS MSV concepting activities was a lengthy design review session conducted over consecutive days. The session was focused on bringing together experts from various application teams to review the complete MSV conceptual design, collaborate on ideas for improvement, and emerge from the session with an improved concept. The design review occurred in 2003 at the Advanced Concept Team offices. Representatives include various participants from the Army R&D community, Army Officers involved with managing the MSV program, and key contractors and industry partners.

Review Process

The first phase of the review was to identify a set of critical success factors for the MSV concept formally called "Standards of Excellence". These standards were comprised of general Army tenets (e.g. "Soldier First" - comfort, safety, accessibility, ergonomics, and maintainability) along with specific metrics and targets in the areas of survivability, vulnerability, designs, and materials.

Once the standards were identified, each major subsystem within the MSV was reviewed by the entire design team. The process involved a facilitator leading a review of the subsystem with discussion in the form of questions,

challenges, and suggestions from the assembled team. During each discussion, a 1/6 scale, table-size model was used to arrange how major subsystems were to be placed within the MGV. Additionally, as changes were suggested from the review panel, modifications were applied to 3D renderings of the MSV displayed on a projection screen to allowed proposed changes to be viewed in real-time. Combined, the desktop model and projected visualization of the concept provided the review team with a compelling set of data to evaluate possible configuration changes for the MSV concept.

Outcomes

Several recommendations from the concept review session were incorporated directly into the FTTS MSV designs. Among the more relevant modifications to the MSV concept included the following recommendations:

- Inclusion of a large panel in the front of the MSV to allow easier access to the engine compartment.

- Separation of the fuel tank into two containers.

- Improved ergonomics and accessibility to the communications module through relocation of the components.

- Modified location and functionality of a "self defense" protection weapon.

- Recommendations for external storage of ammunition.

- Powertrain exhaust routing through the rear of the MSV (the initial concept routed exhaust through the side of the vehicle).

Additional performance information discussed and captured from the review was incorporated into the MSV ACTD performance specification. Further, a "compliance matrix" was developed to compare concept targets to prototype metrics upon completion of the detailed designs and prototype. Figure 4.1 displays a graphical representation of the FTTS MSV concept (Source: U.S. Army Public Release Presentation).
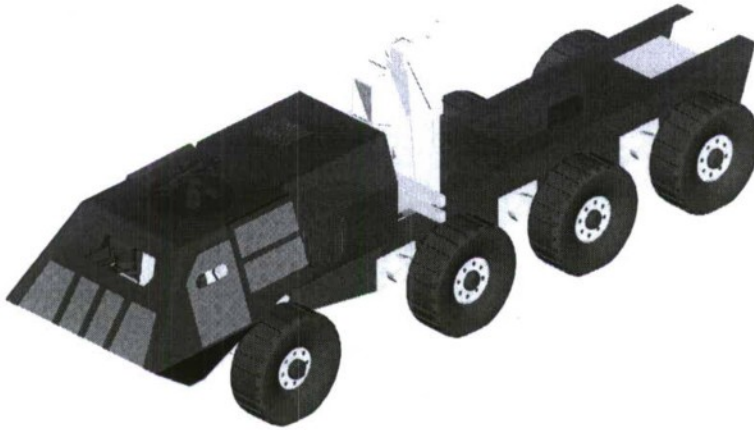

Figure 4.1 FTTS MSV Concept

<u>Relevance</u>

The FTTS MSV design review represents a single point in time where key decision-makers and experts met together to openly collaborate on improving the concept. The expert interaction among decision-makers represents "the pinnacle" of information assessment to make sound concept decisions.

<u>Research Application Opportunity</u>

The interchange that occurred between key program players provided a level of insight to relevant factors important for capture in a decision-support framework. Using data points from the review (process, component decisions, and relevant inputs), the CSCW prototype attempted to simulate the concept review process to provide a decision maker with relevant information to possibly influence the action similar to an expert who participated in the review session. Specifically, the approach was to use the framework to create a prototype to support concept decision making by mapping data similarities through comparing attribute information on an ACT data set, simulated past decisions, and other relevant data points.

Study II: Multi-Purpose Crane

An important concept emerging from the FTTS MSV design was a multi-purpose crane providing a variety of cargo processing operations currently handled by several different pieces of equipment. The multi-purpose crane

allows the MSV vehicle to completely back up into target transport aircraft (e.g. C-130), remove cargo off the plane, and provide capabilities similar to a forklift to move and arrange cargo (either onto a vehicle, ground, or other equipment).

Background

Although the MSV multi-purpose crane was an original concept, the origins of the concept were based in part on the realization of non-FTTS requirements and information from precursor vehicle systems. Requirements contributing to the crane originated from a broad Army-wide initiative directed at streamlining systems and reducing the amount of material handling equipment (MHE) used for cargo handling. The multi-year initiative known as SMART (Simulation and Modeling for Acquisition, Requirements, and Training) has the goals of reducing the time, resources, and risk associated with the acquisition process while increasing the quality and supportability of fielded systems [127]

Another contributor to FTTS MSV multi-crane concept is the palletized load system (PLS) currently deployed in several configurations on the Army's HEMTT-class (Heavy Expanded Mobility Tactical Truck) transport vehicles. The PLS consists of a rear-mounted material handling crane (MHC) with the ability to "hook and pull" standardized containers and pallets back onto itself. Figure 4.2 provides a view of the PLS system on a M1076 HEMTT with a 16.5 ton payload (Source: U.S. Army Public Release)

Figure 4.2 HEMTT PLS Loading a Standard Container

Relevance

The FTTS MSV smart crane extends beyond the singular capabilities of the HEMTT PLS "hook and pull" concept by providing the ability to lift and arrange pallets through the addition of lifting arms analogous to standard forklift functionality. The additional functionality allows cargo to be loaded and carefully arranged either onto the MSV or to other cargo vehicles. The FTTS MSV multi-purpose crane also has several pre-programmed motion sequences to allow the device to be quickly extended to certain distances without having an operator control every element of the sequence. Additionally, the FTTS MSV is designed with a "variable height" suspension to allow the chassis to adjust to different levels as needed to manipulate cargo (such as elevating to the height of C-130

decks). The FTTS MSV multi-purpose concept crane is shown in a rendering in Figure 4.3 (Source – U.S. Army Public Release)
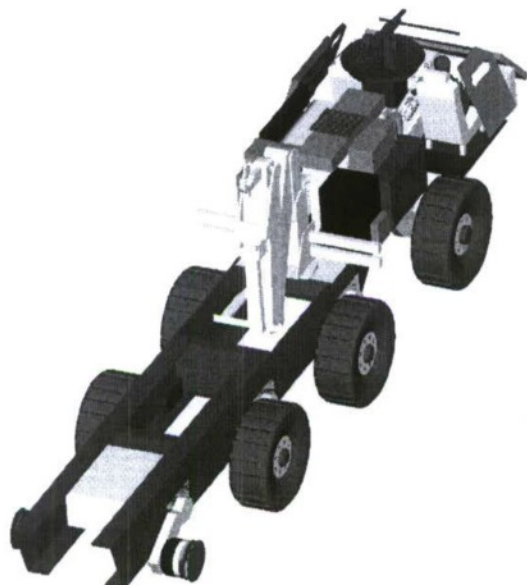

Figure 4.3 FTTS MSV Multi-Purpose Crane

The FTTS MSV multi-use crane is intended to improve loading and unloading time by reducing the need for additional pieces of equipment, reduced maintenance times and costs (on individual MHE systems like the K-loader and forklifts), and reduction of the number of necessary personnel for material handling. Because a transport airplane may be force to land in a "hot spot" e.g. an active military theater, current MHE equipment such as K-loaders and forklifts may not be suitable for manipulating cargo. Therefore, the MSV multi-use crane

allows equipment to be moved in locations previously not possible with standard MHE equipment. Currently, the FTTS MSV multi-purpose crane is being produced in fully-functional prototypes by Stuart & Stevenson, a defense contractor [128].

Research Application Opportunity

The FTTS MSV multi-purpose crane provided a specific example where requirements combined with contributions from existing systems can be used in the development of a successfully concept. Similar to the method taken with the FTTS MSV concept design review study, the approach for applying the framework model to the multi-purpose crane was to create a prototype to simulate the concepting activities and provide potentially important data to a decision maker through data filtering.

CSCW PROTOTYPE DEVELOPMENT

Upon identifying targets for application of the research, the process of developing a prototype environment based on the core elements of the framework was undertaken. Development of the prototype followed each of the core elements in the preferred order of application.

Identification of Core CSCW Environment

The first step in the creation of a prototype was the selection of an appropriate CSCW software environment to serve as the foundation for the framework architecture. Functionality from commercially available software systems that could be leveraged as a prototype foundation can be found in Document Management Systems (DMS) such as Documentum and Adobe, Business Process Management (BPM) such as BEA and Sterling, portal environments such as Microsoft SharePoint and IBM WebSphere, and Product Lifecycle Management (PLM) system [129]. Additionally, tools such as Wiki's are gaining popularity as collaboration environments as teams move toward "openly-managed" approaches to information sharing [130]. For this research, the commercial application Windchill, a PLM architecture from PTC, was selected for use as the CSCW prototype architecture. Windchill provides the ability to create and organized a data schema based on an object-oriented hierarchy and metadata [131].

The choice of the Windchill architecture also served to facilitate selection of several other required CSCW components. The Windchill environment natively 'bundles' several software products with functionality previously identified that is necessary to support the CSCW architecture, including a search engine, Web services, and process standardization tools. The CSCW system based on the Windchill environment was deployed onto a single, Windows-based computer system. The framework architecture after deployment is represented in the diagram provided in Figure 4.4 (source – PTC).
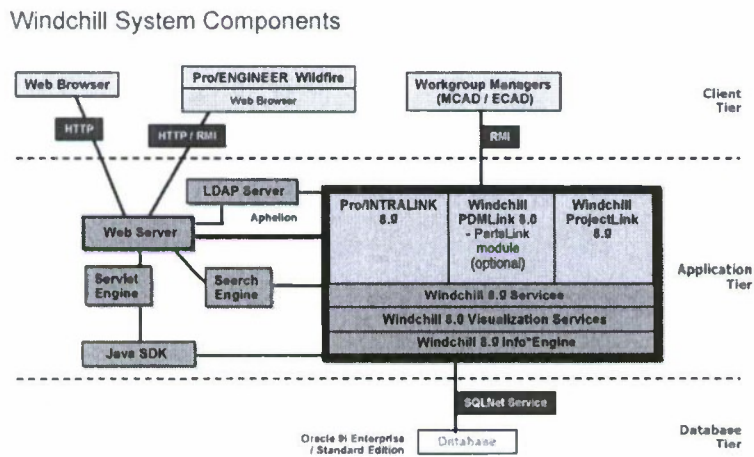
Windchill System Components

Figure 4.4 CSCW Framework Architecture

Upon deployment of the architecture, additional configuration focused on the creation of attributes for capturing metadata for use in filtering decision-based information.

Data Characteristics and Hierarchy

As previously described, another important activity within framework deployment involved identifying a data hierarchy for managing concept related information. The approach used was to analyze the information to be managed within the prototype and propose a hierarchy to optimize data storage and access. A prerequisite activity was to understand the information mass managed by the Advanced Concepts Team (ACT). The ACT has implemented a variety of data storage and 3-D information systems facilitating full-range modeling and concepting activities. Among core tools use for information management within the ACT is the Advanced Collaborative Environment (ACE). The ACE is a portfolio of design tools based, in part, on a Windchill environment and used to manage concept information (designs, documents, and presentations) [132].

An assessment of Advanced Concept Team information managed with ACE revealed approximately 2800 ACT unclassified data items. Data items included legacy requirements, concept information, renderings, models, test data, academic papers and trade studies. Also managed within the ACT data environment were a large number of data items appearing to have no value within the reuse principles being proposed - biographical statements, maps, agendas, forms, organization procedures, and non-work related information. Finally, a substantial amount of duplicated (or near-duplicated) information was identified within the data set. Using a subset of the information representing the

most relevant data to the framework, a data set consisting of approximately 900 items was extracted for use within the prototype environment.

Historically, the Advanced Concepts Team has not relied on workflow-related decision processing for concept development and approval activities. Therefore, very little explicit ACT "decision-related" data was identified in the ACE environment – which was expected since most organizations do not historically capture past decision points in a manner which would facilitate direct reuse. Although the lack of explicit decision data impacted the prototype from the perspective of transparent correlation to the root data set, the volume of information extracted from the ACT subset still provided a robust test bed for analysis.

Another important element of the ACT data analysis was a review of the existing categorization structure and hierarchy in the ACE. The 'state' of the data hierarchy revealed a large number of information stores that have grown fairly 'organically' over time - meaning the data structure appeared to evolve over time with localized (non-holistic) planning for data management. A generic representation of the ACT information hierarchy is shown in Figure 4.5. Due to the sensitive nature of the data leveraged by the ACT, the categories shown in Figure 4.5 have been generalized.

As previously described, the structure of the CSCW information hierarchy becomes an important element in the ability to extract relevant information for the decision maker. Considered in aggregate, the Advanced Concepts Team information hierarchy managed within ACE supports opportunities to provide

details on concepts which could as reference to the team. In the observed state, the data hierarchy showed substantial information category overlap, redundancy, and inconsistency among topics – which has probably hindered the use of historical data among the team. As represented in Figure 4.5 with the summary representation of the ACT data hierarchy, duplicate classes of information exists in different locations (e.g. studies, modeling and simulation data, conference and technology briefings, photographs, videos). Based on the interpretation of the survey data discussed in Chapter 3, one conclusion of the analysis can be finding or discovering relevant ACT information should be improved through adoption of the framework principles outlined in this research.
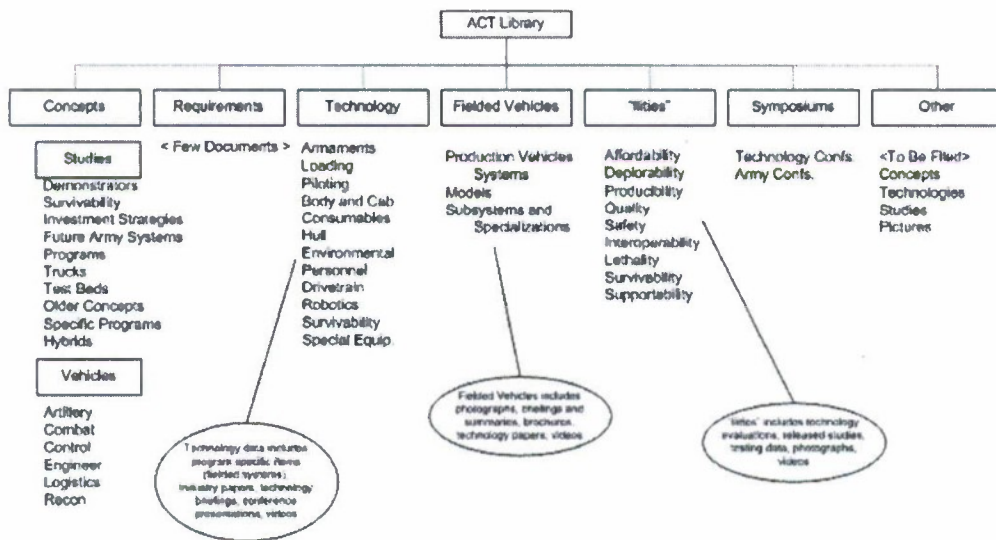

Figure 4.5 Representation of Existing ACT Data Hierarchy

Using the hierarchy analysis as a basis, the CSCW prototype was designed with an approach for managing information stores using a "matrixed" construct. As described in Chapter 3, the characteristics of the data itself provided a path for determining a structure. The existing hierarchy can be divided into two categories based on either entity or descriptive characteristics. From the entity perspective, three major categories of data were identified based on the ACT data characteristics analysis:

- *Programs* such as the Future Tactical Truck System (FTTS)

- *Concepts* as related to specific military systems or subsystems (in a fielded, prototype/experimental, or "future needs" state of development).

- *Technologies* for use within concepts (such as materials and powertrain fuels).

From the descriptive perspective, two major categories of information were identified.

- *Details* - Program-related data typically classified as requirements, program management documents, specifications, etc.

- *Characteristics* – Types of studies conducted on concepts or programs (e.g. survivability, weight, maintainability).

The major categories and key sub categories of the ACT data set is provided in Figure 4.6. Additionally, classes of information related to conferences, industry briefings, and academic events are also accounted for among the categories.

Objective Categories			Subjective Categories	
Program	Concept	Technology	Details	Characteristics
FTTS	Transporters	Powertrain	- Requirements	- Survivability
FCS	Trailers	- Standard Power	- Specifications	- Lethality
FSCS	Unmanned Systams	-- Gasolina	- Reviews	- Weight
LTV	Aquatic	-- Diasal	- Models	- Range
HMMWV	Aerial	- Alternativa Power	- Simulations	- Maintainability
HEMMT	U.S. Govarnment	-- Hydrogan	- Program Managament	- Dimensions
TANK	Foraign	-- Solar	- Field Raports	- Payload
- M1A1	Academic	-- Electric	- Engineering and Dasign Notices	
- Bradley	Weapons	-- Electromagnetic		
LEGACY	Ammunition	- Tranmission		
		Robotics		
		Datection		
		Communication		
		Vatronics		
		Intelligent Systams		
		Armor		
		Matarials		
		Motion		
		- Whaeled		
		- Tracked		
		- Othar		

Figure 4.6 Major Categories and Sub-Categories of the CSCW Prototype

As mentioned in Chapter 3, representing a matrixed data hierarchy can be complicated within a computer environment more suited to a simple, top-down data hierarchy. Although a matrixed hierarchy can be implemented through the use of proxy references (such as pointers and links) so data is not physically replicated, transposing a portion of the matrix into a traditional hierarchy provided for better traversing and maintenance. Therefore, within the prototype several descriptive categories (related to Details and Characteristics) were transposed

as subordinate to the entity categories. Although the transposed structure did create duplicate sub-categories in the literal sense, the uniqueness of the higher-level categories eliminated problems of duplicating or miscategorizing data items. Figure 4.7 provides a partial view of the transposed data hierarchy as displayed from the CSCW prototype.
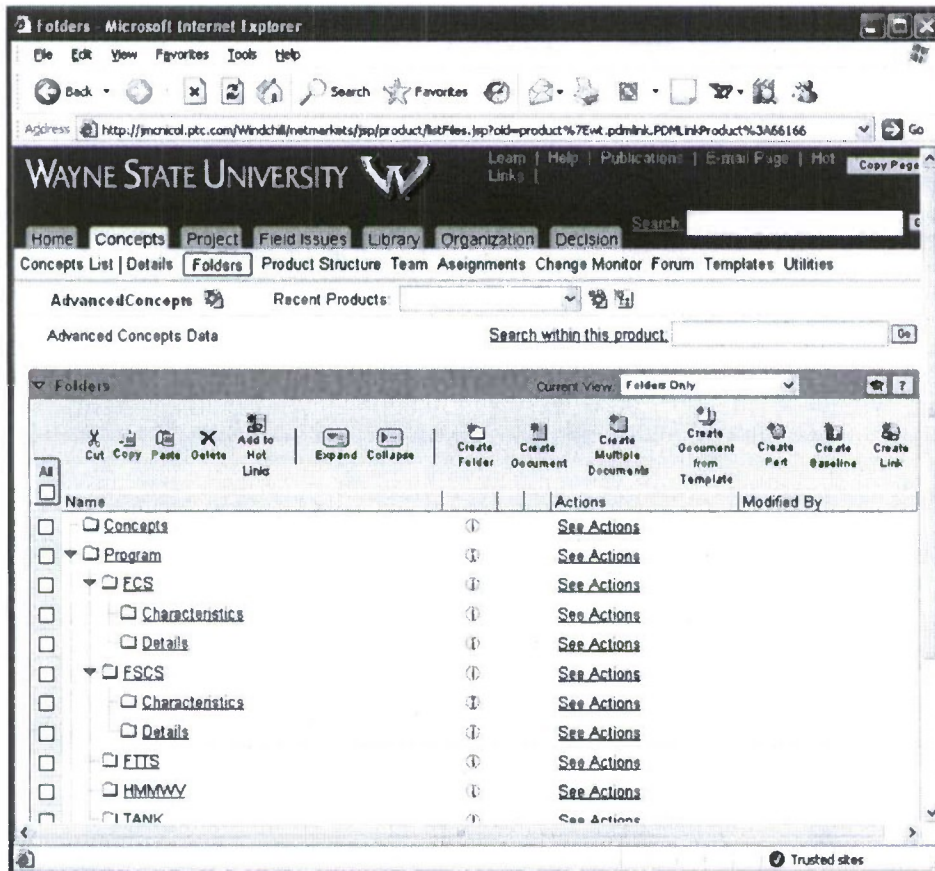
Figure 4.7 Transposed Data Hierarchy within the CSCW Prototype

Content Filtering Attributes

Content filtering attributes provide an important measure for identifying data that could be leveraged to assist in decision-making activities. In the data subset extracted from the Advanced Concept Team (ACT), each item is managed using a generic set of metadata attributes such as a title and short description. With a generic schema there are few opportunities to distinguish information for rapid location and discovery, and identifying specific data items therefore relies heavily on content indexing via search engines. Within the prototype, several attributes were added into the data hierarchy for each managed item as indicators for possible data reuse. The list of extended attributes included the following metadata:

- Program or Platform
- Concept Type
- Vehicle system or subsystem
- Analysis Type
- Key Outcomes
- Critical Requirements
- Age/Relevancy Period

Of the attributes listed, "Age/Relevancy Period" provides a significant criterion on which data can be filtered since time sensitivity plays an important

role for data relevancy. Within the ACT data set, technological advances have a substantial impact on concept obsolescence. However, many elements from legacy studies and concepts (e.g. munitions studies, vehicle test data, motion studies) still can provide relevant references for decision makers.

Process Flows

Advanced Concepts Team process flows were developed within the prototype to route information to participants based on pre-defined work patterns encompassing the overall development state of the concept. Within the CSCW environment, work processing models are included as part of a standard software toolkit. For the Advanced Concepts Team development process, the core steps were encoded into the environment in the form of discrete tasks as shown in Figure 4.8.
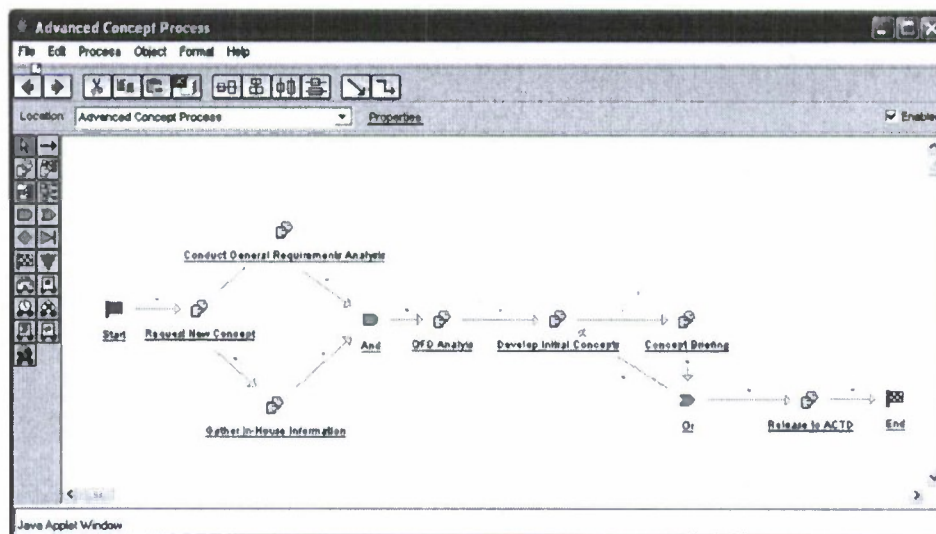

Figure 4.8 CSCW Prototype Process Map

General comments related to the prototype process flow.

- The process initiator (a senior team member, team leader, or manager) determines the type of concept activities to be undertaken. Information describing the concept is also linked to the work process. Based on the items selected, concept development activities in the form of tasks are assigned to members of the concept community. Team members act on the assigned tasks, usually creating or enhancing information.

- It is during the "in-house" search of prior concepts or related information where the first use of the data filtered based on specific attribute information becomes an important element in the generation of concepts. Based on requirements for the concept being considered, data within the CSCW environment will be made available to the developer based on correlated attribute information.

- Upon completion of core development activities, the concept is processed through a series of reviews with internal groups, customers, downstream work teams, or external contractors working with the program.

- As concepts mature and move forward toward customer approval and ACTD, it is at this stage where prior decision data becomes relevant to the reviewers and decision makers. Using the filtering

attribute information and data derived from the three core decision artifacts described in Chapter 3 (cost, timing, and deliverables), reviewers in the activity chain receive past decision data that best corresponds to the decision in hand. Reviewers can traverse returned decision objects to view related outcomes, including effects over time.

- Ultimately, a decision will be reached on the concept under development. In making the decision, the task owner provides information related to the core criteria that helped drive the decision forward. The data captured will be managed on the decision object, along with meaningful links to items that best represent a data, creating a narrative over time describing both "up to the decision point" perspective as well as "what happened after" history (prototyping, production, maintenance, engineering changes).

Development of the Decision Object

The decision object represents a common holder for information as it pertains to the decision. Within the CSCW environment, object-related data that best provides a holistic perspective on the evolution of a concept includes documents, parts, products, CAD files, and engineering changes. It is assumed the application of the decision object is transparent to the specific types of objects managed within the CSCW environment. Stated another way, the decision object should be able to adapt and make reference to the object hierarchy of any CSCW environment where it is being applied.

As described by Ulrich and Eppinger, data is typically more subjective (specifications and requirements) and design 'simplistic' (renderings and sketches) in the concept development phase than in later phases (where complex CAD designs and Bills of Material representing the final products are used extensively) [2]. Therefore, data anticipated for use in a new concept decision-making activity will likely be more descriptive-based than math-based (CAD and 3D renderings). Conversely, once a concept has moved into later stages of product development, representative data elements will include CAD data, part structures, and engineering change data.

Combined, the complete descriptive range of these objects represents the life cycle of a product. Within this framework, it is presumed decision makers will benefit from seeing subjective data used in making a concept-related decision as well as the results - the 'effect' – of the concept after being produced and fielded.

In many enterprise environments, much of the data representing the "success of failure" cf a fielded concept can be best located in external systems such as financial databases, warranty claim systems, and reliability reports. Product design-oriented systems can leverage design revisions like engineering changes for similar indicators. For of the framework prototype, "result indicators" were confined to the subset extracted from the ACT data system.

In the context of the prototype CSCW environment, the decision object as described in Chapter 3 was design to provide mechanisms to traverse most, if not all, of the core object types (drawings, photographs, presentations). In object-oriented application development, an advantage of leveraging an object-based hierarchy is the ability to extend a base object having existing desired characteristics in order to supplement with specific, intended behavior [133].

Within the Windchill environment, an object called WTDocument (General Document) was extended using UML modeling tools to provide decision harnessing capabilities into a new object (called "ConceptDecision" or "Decision" by its common reference). The decision object was extended to retain three core elements captured from the decision - cost, timing, and deliverables – and other attributes described in Chapter 3 for decision and content filtering (milestones, end state, etc.). Figure 4.9 provides the UML diagram of extended decision object from based object WTDocument.
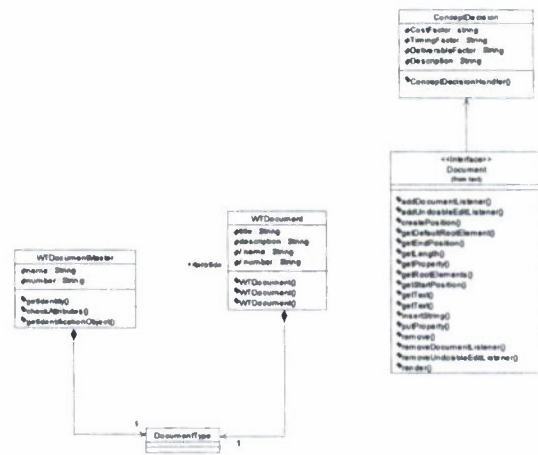
Figure 4.9 Extended Decision Object for the CSCW Prototype

A key behavior ConceptDecision directly inherited from WTDocument was the ability to create persistent linkages with other objects. Additionally, ConceptDecision can have relationships with workflow-based objects (WTWorkflow) where specific activity and action information is persisted. The decision object (ConceptDecision) was designed for exposure in the graphical user interface (GUI) through modification of existing HTML, JSP, and XML templates.

Decision and Risk Items in the Prototype

Within the prototype, risk will be measured using a subjective evaluation against a specific target decision data item. Although it is plausible that using subjective measures are not nearly effective as numerically-based indicators, the

returned risk items in the CSCW prototype should offer an additional perspective on outcome to concept development decision makers.

As mentioned earlier, the Advanced Concepts dataset extracted from ACE did not have explicitly called out data items related to prior decisions or risk elements. In order to satisfy the need for having decision and risk data within the prototype to simulate concept decisions, data items found to best represent an approximation of final decision were entered into the prototype as "decision objects". Similarly, items from the ACT data set having attribute information best resembling a problem report, issue, or change were entered into the environment as risk items. Risk items created within the prototype included engineering design reports, problem reports captured from the field, test incident reports, and external items such as articles, trade studies, or academic papers.

Decision Advisor

To assemble all key relevant decisions, data items, and risk elements together into a format that can be quickly leveraged by a decision maker working a concept development activity, a "Decision Advisor" module was developed. The module was based on linking formatted outputs of several independent, but complex data queries together in a single interface. The query parameters are based on passing key parameter data at runtime. A view of the Decision Advisor interface is provided in Figure 4.10.
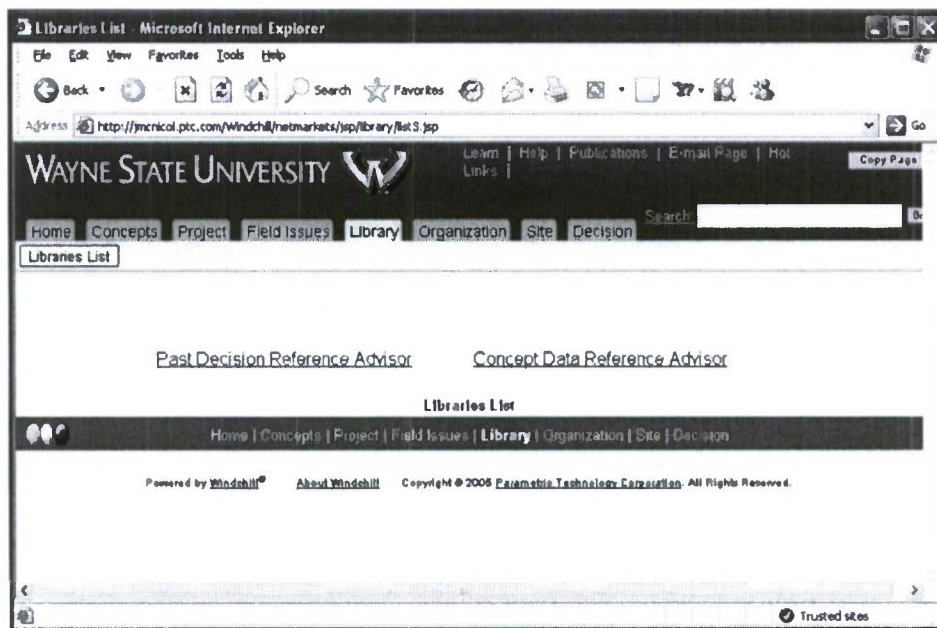
Figure 4.10 CSCW Prototype Decision Advisor Interface

Using the Decision Advisor, data can be accessed for easy reference by the decision maker. Figure 4.11 displays output from the advisor for decisions involving the FTTS program.

Figure 4.11 CSCW Prototype Decision Advisor Filtered Data Report

CHAPTER 5 – RESULTS AND ANALYSIS

This chapter describes outcomes from prototype environment simulations with data representative of the case studies described in Chapter 4. The evaluation approach for each example will be presented, key targets for analysis identified, and results analyzed.

As described in Chapter 4, a CSCW prototype was developed to demonstrate the feasibility of the framework in a concept development environment. Two examples from the U.S. Army Advanced Concepts Team (ACT) specific to the Future Tactical Truck System (FTTS) Maneuverable Sustainment Vehicle (MSV) were identified. The CSCW prototype was developed in a manner consistent with the principles of the framework.

The case study simulations, although representative of the same concept, were applied in two different manners. In the first case study, the purpose of the experiment was to locate information having possible relevancy on the concept review activity. The second case study simulates a decision making activity as related to an aspect of the MSV concept multi-purpose crane. All data used in the simulations (from the ACT data subset) excluded content developed after the period of the FTTS MSV concept development phase (approximately 2003 and beyond). Using FTTS MSV program data captured since original concepting work would invalidated the intent of simulations - attempting to leverage data to make concept-related decisions.

CASE STUDY I: CONCEPT DESIGN REVIEW

A formal design review was conducted in 2003 on the Future Tactical Truck System (FTTS) Maneuverable Sustainment Vehicle (MSV) during the concept development phase. The review covered all system and subsystem concepts of the MSV. As described in Chapter 3, several decisions related to important modifications to the MSV concept were made during the review. Using summary reports and interview information, some of the key concepts modified during the review were identified for use in the framework simulation.

Through using modified concepts elements as the baseline, the approach for the prototype simulation was be to identify data elements from the extracted ACT subset that correlate to the concept or provide relevant perspectives of data possibly useful to the decision maker. Six simulated targets extracted from the MSV design review are summarized below.

1. Inclusion of a large panel on the front of the MSV to allow easier access to the engine compartment.
2. Separation of the fuel tank into two containers.
3. Improved ergonomics and accessibility to the communications module through relocation of components.
4. Modified location and functionality of a "self defense" protection weapon.
5. Recommendations for external storage of ammunition.

6. Powertrain exhaust routing through the rear of the MSV (the initial concept routed exhaust through the side of the vehicle).

Using the CSCW prototype, data from the ACT subset was filtered against the simulation targets and analyzed. Tables 5.1 through 5.6 represent the results of the six test runs to extract relevant information. In each table, the data set includes the original simulated target, returned data items, subsequent analysis of the content (with a description of what was found), an analysis of the returned item with respect to the target to determine whether the item can offer any influence on decisions in the target concept area. The analysis was based reviewing the context of the data item to determine any common areas of interest or duplication – specifically details regarding location or usage of a component, similar requirements, common designs or renderings, or similar functionality,

Run I: Inclusion of a Large Access Panel on the Front of the MSV

Table 5.1 provides a summary of the results of the analysis. In total, fourteen items were returned from the data advisor. Subsequent analysis of each data item showed *none* of the items had relevance to the simulated target area.

Target Description			
Inclusion of a large access panel on the front of the MSV to allow easier access to the engine compartment.			
Data Item Description	Analysis of Content	Comparison Against Target	Relevant (Yes/No)
LK10948 - Front Engine Tank Concept A	Front Engine Tank (LK10948) Concept Summary; dated January 1980. This concept integrates a 120mm external gun, one man turret on to a tracked vehicle hull with front power plant (T-mounted AGT 1500 engine with X1100 transmission).	Tank-related concept	No
M2A2 Iso Drawing (left front view) A Picture	Drawing of the M2A2 Bradley IFV showing the main improvements over the earlier M2A1 vehicle.	Tank-related concept	No
M2A3 with CITV Photograph (front view) A Picture Released2005-02-22 10:46:42 EST	Photograph of the United Defense Bradley M2A3 with Commander's Independent Viewer mounted on the right rear (behind commander's hatch) of the turret.	Tank-related concept	No
M2A3 w/MK44 30mm Cannon Vehicle Prototype Photo (front view) A Picture	Photograph of the United Defense LP prototype installation of the MK 44 30 mm cannon upgrade on a M2A3 series infantry fighting vehicle.	Tank-related concept	No
Vehicle Characteristics - 1950s and 60s A Briefings ReportsReleased 11493 (Vehicle Characteristics - 195	Characteristic Sheets for wheeled and tracked vehicles of the 1950s and 1960s. Includes combat, tactical, and trailers.	An interesting document displaying a history of vechicles developed by TACOM. However, specific information related to access panels was not to be found.	No
FMTV (M1075A1) Characteristics Opposed Piston Opposed Cylinder Engine A	Characteristic Sheet for FMTVA1 M1078A1 2.5 Ton Standard Cargo Truck (LIN T50081, NSN 2320-01-447-8343).	No information related to engine compartment access	No
LK10609 - Protected Squad Carrier w/Front Power Plant A	Protected Squad Carrier w/Front Power Plant (LK10609) Concept Summary. Concept carries 3 vehicle crew and 8 dismount troops		
Anti-Aircraft Gun Vehicle Photograph (right front view) A Picture		Extremely old photograph (pre-1960's), no value	No
Engineer Vehicle Photograph (left front view) A Picture		Extremely old photograph (pre-1960's), no value	No
LC12661 - DFS 94 Front Armor Effects A	Design Feasibility Study (DFS) 94 Front Armor Effects Drawing (LC12661); dated May 1, 1990. This drawing shows the effect of three front armor options on the overall vehicle configuration.	Armored fighting vehicle concept	No
S&S Engineering Model Methodology Workshop (Jun '04) A Briefings Reports	Stewart & Stevenson Engineering Model Methodology Workshop; dated July 1, 2004. This training material was presented to the FTTS Government Working Group July 1, 2004.	Methodology-based activities	No
LK10372 XM1 Tank with Ammunition Compartments A	XM1 Tank with Ammunition Compartments (LK10372) Concept Summary; January 1972.	Armored fighting vehicle concept	No
LC12659 - M2A1 Engine Compartment Envelope DrawingA	M2A1 Engine Compartment Envelope Drawing; dated March 21, 1990.	Armored fighting vehicle concept	No
LC12660 - DFS 94 Engine Compartment Dimensions A	DFS 94 Engine Compartment Dimensions Drawing (LC12660); dated April 26, 1990.	Hard to relate to any particular concept	No

Table 5.1   Results from Test Run I

Run II: Separation of the Fuel Tank into Two Containers

Table 5.2 provides a summary of the results of the analysis. In total, two items were returned from the data advisor. Subsequent analysis of each data item showed *none* of the items had relevance to the simulated target area.

Target Description			
Separation of the fuel tank into two containers			
Data Item Description	Analysis of Content	Comparison Against Target	Relevant (Yes/No)
M1Fuel Tanks (from TM 9-2350-255-10) A General Document Released 9276 (M1 Fuel Tanks (from TM 9-2350-255-	Locations and volumes of fuel tanks in M1. Page taken from TM 9-2350-255-10.	Tank-related layout	No
Lightweight JP-8 Fuel Tank Power Sys for UAV, UGV, & APU A	Lightweight JP-8 Fueled Power Systems for UAV, UGV, and APU Applications Report; dated July 2002. This paper was prepared for the AUVSI 2002 Unmanned Systems Conference (July 9-11, 2002).	Engine-analysis	No

Table 5.2   Results from Run II

Run III: Improved Ergonomics and Accessibility to the Communications Module through Relocation of Components

Table 5.3 provides a summary of the results of the analysis. In total, ten items were returned from the data advisor. Subsequent analysis of each data item showed *three* items having possible relevance to the simulated target area.

Target Description			
Improved ergonomics end eccessebility to the communicetions module through relocation of components			
Data Item Description	**Analysis of Content**	**Comparison Against Target**	**Relevant (Yes/No)**
A Briefings	on Vulnerablllity from e C4I &	High-level overview	No
FTTS Updeted with C4ISR A Anelysis	Weight Study	Weight Study	No
FCS Vetronics end C4ISR Pit Stop Stendards of Excellence A Briefings Reports	Summery informetion on en FCS-releted Pit Stop	Several items raleted to the plecement end wiring of C4ISR equipment	Yes
LC11894 - AFV C4 IEW Vehicle A	Armored Femily of Vehicles (AFV) C4 Vehicle (FV-9) IEW Verient Vehicle (LC11894) Concept Summery; deted July 1987. The C4 IEW Vehicle is integrated onto the 35 ton Medium Chessis.	Fighting vehicle-raleted layout	No
LC11906 - AFV C4 ETAS Vehicle A	Armored Family of Vehicles (AFV) Asseult Support (FV-9) C4 ETAS Vehicle (LC11906) Concept Summery; deted July 1987. The C4 ETAS Vehicle is	Fighting vehicle-releted leyout	No
Feesibility of Using Vehicle's Power Line es CommoBus A Briefings Reports	Feesibility of Using Vehicle's Power LIne es e Communication Bus briefing; deted June 2004. This briefing was prepered by Weyne Stete University at the 4th Annuel Intelligent Vehicle Systems Symposium, 21-24 June 2004.	Using power lines for transmitting communication-based dete to the C4ISR units	Yes
Becoming en Expert et Architectures (Jun '03) A Briefings Reports	Bacoming and Expert at Architectures - An Iterative Approech briefing; deted June 11, 2003. Briefing presented et the NDIA 3rd Annual Intelligent Vehicle Systems Symposium.	Process-related ectivites	No
FTTS Operationel Modeling Results (TACOM Jul '03) ABriefings Reports	Future Tectical Truck System (FTTS) Operetionel Modeling Results Briefing; dated July 28, 2003.	Side-by-side comperison between the HEMMT end the FTTS concept. Simuletions end numbers provided	Yes
Integration of Autonomous Sys Comp Using JAUS Architecture A	Integration of Autonomous System Components Using the JAUS Architectura Report; deted July 2003. This peper was prepered for the AUVSI 2003 Unmenned Systems Conference (July 15-17, 2003).	Theoretical overview	No
M4Commend & Control Vehicle (C2V) Brochure A	United Defense brochure	Fighting vehicle descriptions	No

Table 5.3   Results from Run III

Figure 5.1 shows a snapshot of the data from one of the three items (a study from Wayne State University on using vehicle power lines as a communication bus). Note: the data item was classified as "Public Release" by the Advanced Concepts Team.
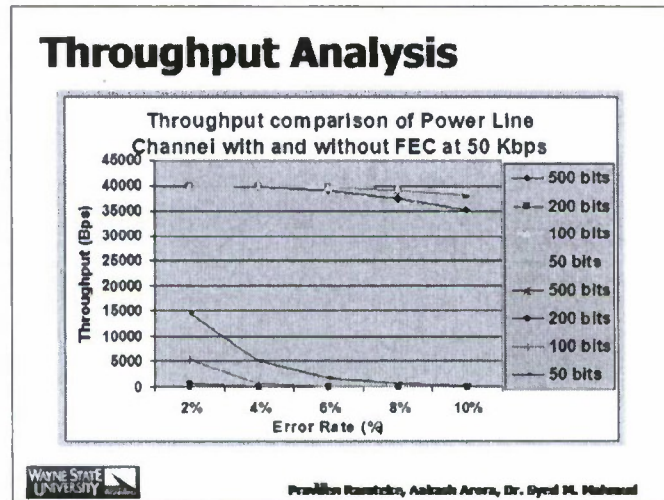

Figure 5.1 Portion of WSU Briefing on Dual Power/Communication Lines

Run IV: Modified Location and Functionality of a Self Defense Weapon

Table 5.4 provides a summary of the results of the analysis. In total, eleven items were returned from the data advisor. Subsequent analysis of each data item showed *three* items having possible relevance to the simulated target area.

Target Description			
Location and functionality of a "self defense" protection weapon			
Data Item Description	Analysis of Content	Comparison Against Target	Relevant (Yes/No)
Evaluation of Gunner Station for Fire-On-The-Move-Phase II	Evaluation of Gunner Station Configuration for Firing-on-the-Move (Phase II) report prepared by US Army Human Laboratory; dated January 1982.	Includes the effects of terrain as well as changes in reaction time due to riders sitting log periods within vehicles.	Yes
Gun Propulsion: Emerging Army Technologies (JPL '88)	This report explores the potential application of Liquid Propellents, Advanced Solids, and Electric gun propulsion technologies to meet the mission	Primarily deals with Howitzer-level gun propulsion	No
M2A3 w/MK44 30mm Cannon Vehicle Prototype Photo (front view) Picture	Photograph of the United Defense LP prototype installation of the MK 44 30 mm cannon upgrade on a M2A3 series infantry fighting vehicle. Photograph is courtsey of Janes.com.	Tank-related photograph	No
ASM Other Heavy Protection Systems Final Report (TCM '93)	Other Heavy Protection Armored Systems Modemization Systems - System Concept and Design Analysis - Final Report; dated August 1993.	Requirements document for armored fighing vehicles	No
Hit Avoidance Regional Protection System (Apr '03)	Hit Avoidance Regional Protection System (HARPS)briefing; dated April 2003.	Overview presentation on e TARDEC technology program.	No
Active Protection System DROZD Video	Active Protection System - DROZD Video (14.42 minutes)	A foreign-made technical video showing various armor attacks and hits over a period of time.	No
Self-Awareness, Monitoring, Diagnostics & Prognostics A Briefings Reports	Self-Awareness, Monitoring, Diagnostics & Prognostics for Intelligent Vehicle Systems briefing	General overview of using sensory data for monitoring health of vehciles	No
UGV Mobility and Self-Protection (Apr '03)	Unmanned Ground Vehicle (UGV) Mobility and Self-Protection briefing; dated April 29, 2003. Briefing presented o the Army Science Board, Platform and Weapon Systems Panel.	Three important information points applicable for the FTTS concept. (1.) Maneuverability over rough terrain, (2.) Ground clearance pros and cons, (3.) impact points for ground explosive (e.g. land mines)	Yes
Self-Awareness, Monitoring & Diagnosis for Autonomous Vehicla Operations	Self-Awareness, Monitoring & Diagnosis for Autonomous Vehicle Operations Report	General overview of using sansory data for monitoring health of vehciles	No
Small UAV Weaponization (AUVSI_Final)	Use of Alternative weaptons.	Aerial weapons	No
Weapon Systems Handbook 2005 (narratives)	Description, specifications, program status, and projected activities for currently fielded weapon systems. Hendbooks from previous yeer can be found as attachments	Very good overview of technology capabilities within the Army	Yes

Table 5.4   Results from Run IV

Run V: Recommendation on External Storage of Ammunition

Table 5.5 provides a summary of the results of the analysis. In total, two items were returned from the data advisor. Subsequent analysis of each data item showed *one* item having possible relevance to the simulated target area.

Target Description			
External Storage of Ammunition			
Data Item Description	Analysis of Content	Comparison Against Target	Ralavant (Yas/No)
Stretched M113A1 Ammunition Storage	Ammunition Stowage in Stretched M113A1 using Ammunition Containers. Concept Summary; dated August 7, 1978	This document was produced in 1978 for the M133A1 vehicle. What is interasting is the information and datails as to how large-caliber shells are stacked and arrangad for storage within tha vehicle. Consideretions for weight (ability to load and unload)	Yes
Explosive Reactive Armor Sketch	Simple sketch of tha affect of armor against axplosiva - layars of extemal armor affected	Sketch was too simpla for understanding, relatad mora to extemal armor.	No

Table 5.5   Results from Run V

Run VI: Powertrain Exhaust Routing from the Rear of the MSV.

Table 5.6 provides a summary of the results of the analysis. In total, three items were returned from the data advisor. Subsequent analysis of each data item showed *none* of the items had relevance to the simulated target area.

Target Description			
Powertrain exhaust routing out of the back of the MSV			
Data Item Description	Analysis of Content	Comparison Against Target	Relevant (Yes/No)
On-Board Vehicle Power Briefings Reports	Briefing presented at the Joing Service Power Expo, May 2005	General overview of the state of powertrain vehicles in the military	No
Power Assessment & Distribution Briefings Reports	Power Assessment & Distribution briefing, deted May 2-5, 2005. This briefing was presented et the Joint Services Power Expo on May 2-5, 2005.	Designing power systems for distribution ecross the vehicle	No
Single Regime Power Split Trensmission for Militery Vehicles	Single Regime Power Split Trensmission for Heevy Duty Militery Vehicles peper, dated June 2005. This paper wes prepered for the 6th Intemetionel Ali Electric Combet Veicle Conference 13-16 June 2005	Related to power issues faced by hybrid end fuel cell vehicles	No

Table 5.6   Results from Run VI

Analysis of Case Study I

The results of the six runs provided an accurate portrayal of the makeup of the ACT data subset since the results included a variety data items – photographs, videos, drawings, concept documents, presentations, and external reference material. A snapshot of the overall results from the six runs is provided in Table 5.7.

Run Number	Target Description	Number of Returned Results	Number of Relevant Items	Percentage of Hits
I	Inclusion of a large access panel on the front of the MSV to allow easier access to the engine compartment.	14	0	0.0%
II	Separation of the fuel tank into two containers	2	0	0.0%
III	Improved ergonomics and accessability to the communications (C4I) module through relocation of the components	10	3	30.0%
IV	Location and functionality of a "self defense" protection weapon (gun or other)	11	3	27.2%
V	External Storage of Ammunition	2	1	50.0%
VI	Powertrain exhaust routing out of the back of the MSV	3	0	0.0%
	Total	42	7	16.7%

Table 5.7 Summary of Runs for Case Study I

From the analysis, three of the runs yielded results having no relevancy to the target area in question. Besides an obvious consideration of the ACT data subset possibly not having enough data to support the three simulation runs, another possible reason why no data was found is due to the nature of the modified target. It is likely the modification recommendation originated from a functional or "downstream" reviewer with substantial knowledge of field-related domain expertise not typically found with the concepting team.

In contrast, three runs did yield data items that, on initial analysis, had enough similarities to the simulated targets to warrant consideration. In further support of the previous hypothesis where "domain expertise" is a factor, the three runs were all related to general functionality and subsystem location—common themes in envelope design during concept development. Therefore, it is feasible to assume these general topics have been covered during prior concepts development activities and data elements representing outcomes are part of the ACT body of knowledge.

Of all returned data items showing relevance in the test runs, the item of most interest is likely from *Run V (External Storage of Ammunition)*. The data item was from a study conducted in 1978 on an armored fighting vehicle (M113A1). While the vehicle itself has little correlation with the FTTS-MSV, it is the analysis of how ammunition should be stacked and arranged for firing, including container sizes of the ammunition and the process for inserting and removing ammunition cartridges that may be of significant interest to a concept decision maker.

Analysis of Case Study I with the Advanced Concepts Team

The results of the simulation runs were reviewed with members of the Advanced Concepts Team (ACT) for further analysis and comment. The hypothesis supporting domain expertise playing a role in the identification for modified items was supported by the (ACT). Further, the data item from Run V described above (1978 M113A1 ammunition analysis) generated the most individual discussion, since the team agreed it may have some interesting data points. The team also confirmed the item had not been considered in development of the MSV concept due to the age of the study.

CASE STUDY II: CONCEPT DECISION

The second case study with the FTTS MSV concept involved the development of a multi-purpose crane consolidating several material handling operations. For this case study, a concept-level decision was simulated which encompassed the use of several key framework and prototype features. In the role of a decision maker, a decision task was be assigned to review the multi-purpose crane concept and determine whether proper considerations have been made prior to moving forward into further design work. To complete the simulated decision, three areas related to the decision activity were addressed.

- Interpretation of key requirements forming the "background" of the decision.
- Review and identification of relevant data obtained through decision advising applications.
- Creation of a decision object linking need, decision, and result.

Key Requirements Background

The list of requirements for the FTTS MSV, many of which also impact the multi-purpose crane, was extensive. A detailed list of requirements can be found in the *FTTS-MSV Emerging Desired Capabilities* document [134]. The partial list below provides some insight to the types of requirements supported by the

material handling system in the concept. Many of the requirements listed were also used to create the "needs" linkages on to the decision object accompanying completion of the workflow activity.

- Allow the MSV vehicle to physically back up into a target transport airplane (e.g. C-130), remove cargo material directly off the plane, and provide capabilities similar to forklift to move and arrange cargo as necessary. [134]

- Allow cargo to be loaded and arranged either on to it or to other cargo vehicles. [134]

- Facilitate several pre-programmed motion sequences to allow the crane to be quickly extended to certain distances without having an operator control every element of the sequence. [134]

- Support a "variable height" suspension to allow the chassis to adjust to the level needed to manipulate the cargo. [134]

- Support SMART initiatives for reducing material handling systems throughout the Army [127].

- Improved load and unload time [134]

- Reduced need for additional equipment [134]

- Reduced maintenance times and costs [134]

- Reduced number of personnel necessary for material handling. [134]

- Support load and unload operations in rough terrain [134]

- Support landings in "hot spots" e.g. active military theaters [134]

- Support for cargo payload capacity of 11 tons. [134]

- Maximum load capacity (cargo and vehicle) of 13 tons [134].

Review and Identification of Relevant Data

With requirements in hand, the CSCW prototype was leveraged to determine if there are items within the existing data set which may possibly influence the opinion of the decision maker. With reference to Tversky's concepts of bias [102], it was considered important to identify relevant information within a small number of initial reference points. Prototype information was harnessed from the following sources:

- Data elements from the CSCW prototype based on metadata and content extracted from the Advanced Concepts Team's data set.

- Decision and risk data elements simulated within the CSCW prototype environment.

Ultimately, the simulations ran in the prototype were intended to answer the following questions:

1. Does any background information exist related to either for the FTTS program or any other system serve as a precedent for the multi-purpose crane concept?

2. Can any past decisions offer guidance?

3. Are there aspects of the concept should merit cause for concern?

The first simulation was intended to locate data items having relevance to the decision on the multi-purpose crane. Using a limited amount of key concepts (PLS, pallet, crane, cargo), a set of data was filtered from the prototype analysis tool. Table 5.8 provides a summary of the results of the analysis of locating relevant data items. In total, thirteen items were returned from the data advisor. An analysis of the data determined *five* of the items had relevance to the multi-purpose crane decision activity.

Target Description - Reference Data			
Multi-Purpose Crane for the FTTS-MSV			
Data Item Description	Analysis of Content	Comparison Against Target	Relevant (Yes/No)
LK10998 - Weight Comparison LK10998 v M1E1 A M&S Data	Weight comparisons (overall and broken down by functional areas) Advanced Concepts	Comparison of Tank Systems	No
Smart Distribution (3Dec02) Briefings Reports	Smart Distribution - A System of Systems for the Objective Force briefing; dated December 3, 2002. This briefing was presentedat the FTTS industry Day (3Dec02).	Describes the objectives of SMART in relation to material handling. Entire presentation is relevent to the mulit-purpose crane	Yes
Dynamic Analysis of PLS	Computer-Based Dynamic Parformance Analysis of the Palletized Load System (PLS) Transporting PLS Concept Variants	Extremely technical paper describing the effects on the palletized load system. Technical data relevant from load vs. center of gravity and other studies	Yes
M1076 PLS Trailer Photograph (left front view) A Picture	M1076 PLS Trailer Photograph (left front view). Please note that this photograph (minus background) is also attached as secondary content at the bottom of this page	Picture of trailer. No information related to cranes	No
PLS Container Handling Unit Specifications A Picture	Palletized Load System (PLS) Truck and Container Handling Unit Brochures and Pictures; dated 2000.	Shows the "Hook and Lift" features of the HEMMT	Yes
PLS Engineer Variants Requirements & Concepts Report ('96)	Palletized Load System (PLS) Alternative Engineer Uses Requirements Definition and Concepts Report; dated December 1996.	Prioritized load system requirements, including a QFD analysis.	Yes
PLS Alt. Engr Uses - Requirements, Concepts, & Schedule	Palletized Load System (PLS) Alternative Engineer Uses - Requirements Definition, Concepts, and Alalysis Schedule	Timeline-based chart	No
ATLAS Photograph (left front view w/pallet) A Picture	All Terrain Lifter, Army System (ATLAS) Photograph (left front view w/pallet).	Front-loaded pallet mover. Not required as part of the MSV.	No
M915 - Palletized Loading System Demostrator (Jun '03)	M915 - Palletized Loading System Demonstrator briefing; dated June 11, 2003. Briefing presented by at the NDIA 3rd Annual Intelligent Vehicle Systems Symposium.	Various technologies related to a trailer	No
Palletized Load System (PLS) Specifications Brochure	Palletized Load System (PLS) Specificetions Brochure	Strongly focused on the overall vehicle rether than the crane.	No
Palletized Load System Video	Palletized Load System Video (13.44 minutes); dated about 1996	A lengthy video showing the complete loading and removal of pallets on the HEMMT using the "hook and pull" method. An axcellent primer on existing technology.	Yes
M809/M813 Cargo Truck	3 view drawing of the M809 chassis and characteristic sheets for the M813 Cargo Truck	Dated series of drawings related to traditional trucks	No
FTTS MS 5.5/11 Ton Cargo Truck Characteristics	Future Tacticel Truck Systems (FTTS) Maneuver Sustainment 5.5/11Ton Cargo Truck Concept Characteristics Sheets.	Early rapresentation of the FTTS MSV without the multi-purpose crane concept	No

Table 5.8. Relevant Data Items for the Multi-Purpose Crane

The five relevant data items were found to contribute in areas of material handling problems with existing equipment or validation of FTTS-MSV requirements. An example of content cited as possibly relevant was provided in Figure 5.2, an extracted from an overview of SMART distribution requirements (Source – U.S. Army TACOM Public Release).
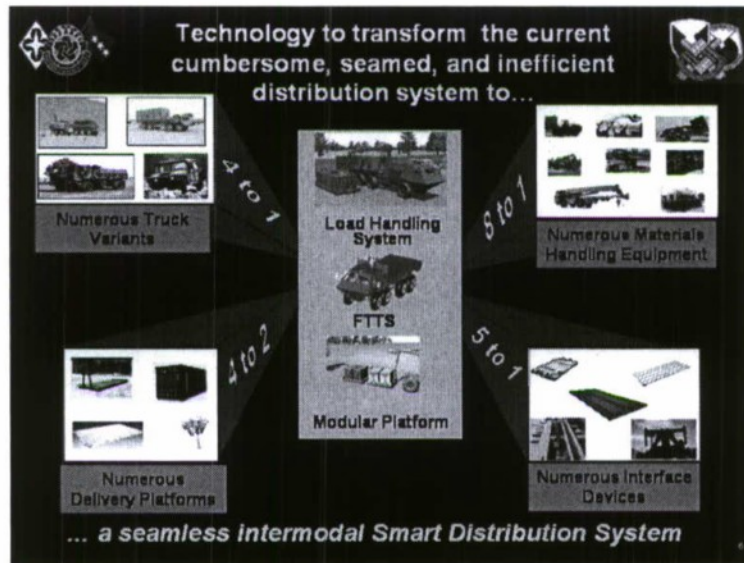

Figure 5.2 SMART Distribution Requirements

The second simulation was directed toward finding past decisions meriting consideration with regard to the crane-related concept decision. As mentioned in Chapter 4, the Advanced Concepts Team (ACT) has not explicitly practiced capturing decision-related information in a manner consistent with this framework. Upon analysis of then ACT data subset, items appearing to be better

suited toward an "outcome" were subsequently created within the prototype as a "decision" object.

Table 5.9 provides a summary of the results of the simulation for locating decision-related items. In total, four items were returned from the decision advisor. An analysis of the data determined *one* of the items had relevance to the multi-purpose crane decision activity. The relevant data item was a summary related to early modeling and simulation activities on the FTTS concept, including information specific to the material handling functionality.

Targat Description - Decision Data			
Multi-Purpose Crane for tha FTTS-MSV			
Decision Item Description	Analysis of Decision	Comparison Against Target	Raievant (Yes/No)
Lesson from Past for Safer Future Tactical Veh.(Jun'03) A Briefings Reports	A Lasson from the Past for Safer Future Tactcai Vehicle briefing; datad Juna 11, 2003. NDIA 3rd Annual Intalligent Vehicle Systems Symposium.	General call for mora safety with number on accidents.	No
FCCVS (Ph 1) Vol VIII Final Report (TCM '82) A	Future Cloase Combat Vehicle System (FCCVS) Volume VIII Final report; datad May 1982.	Detailed study on the effactiveness of short-ranga combat vehicles. No raferences to load handling.	No
FTTS M&S Whita Paper (TARDEC '03) A	Future Tactical truck Systems (FTTS) Modeling and Simulation Whita Paper; dated July 11, 2003. This paper details tha Futura Tactical Truck Systems Modeling and Simulation (M&S) activitias. The paper axplains what has been modeled and how it has been use	Dascription of tha results of initial modeling and simulation for the FTTS. Includas information on simulations conducted with the material handling system.	Yes
FCCVS (Ph II) Vol III Final Report (TCM '83) A	Future Close Combat Vehicle System (FCCVS) Phasa II Volume III Final Report; dated August 1983.	Detailed study on the affectivaness of short-range combat vehicles. No rafarences to load handling.	No

Table 5.9 Relevant Decision Items for the Multi-Purpose Crane

In the final simulation, problem or issue-related data that forms the basis of risk-related information was filtered with Table 5.10 summarizing of the results of the simulation. In total, three items were returned from the decision advisor. An analysis of the data determined *one* of the items had relevance to the multi-purpose crane decision activity. The relevant data item was a journal article published in September 2006 from *National Defense* [135] describing a hybrid power platform used for the load handling system suspension adjustment on the HEMTT class of vehicles. According to the article, a conventional truck has some large drive-train components down the middle of the truck which impact the location of lift handling system. By going with the hybrid approach, the design team was able to embed the load handling system in a manner which would allow the lift systems to be fit within the profile of a transport aircraft (e.g. C-130 class).

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Target Description - Risk Data			
Multi-Purpose Crene for the FTTS-MSV			
Risk Item Description	Analysis of Risk	Comparison Against Target	Relevant (Yes/No)
Netionel Defense Article (2006) - Technology Limitations Stall Military Hybrids	Cautionary tale regerding Hybrid Vehicles - continuing to proof out hybrid power technologies. Also includes some erees where hybrids heve shown success.	Very interesting erticle. Near the end, there is discussion on how the hybrid has hed the greatest success for veriable height suspensions (to reise besed on the height of the C130.) where conventionel trucks heve problems. This directly impects the des	Yes
Stryker - Reports Cite Problems with Vehicle (2005)	Severel risks cited with the Strkyer vehicle - some trivel to potentielly major concems	Nothing related to material hendling equipment (not applicable to the Stryker)	No
RAND - Problems in Army Vehicle Maintenence	A RAND report from 1981 on problems related to the maintenance of Army vehicles. Problems include menpower, training, equipment design, and management	Lessons may still be valid for training end meintenence, but nothing related to meterial handling systems	No

Table 5.10 Relevant Risk Items for the Multi-Purpose Crane

Creation of the Decision Object for the Activity

Using the simulation results returned from the decision advisor, information was saved to a decision-oriented object to denote key characteristics of the decision. Table 5.11 summarizes elements of metadata captured on the decision object.

Attribute Name	Value
Name	Decision - FTTS Multi-Purpose Crane
Title	Multi-Purpose Crane Information Analysis
Description	Review of information supporting the FTTS MSV Multi-Purpose Crane
Cost Considerations	None
Timing Considerations	None
Deliverable Considerations	Please refer to the attached issue in relation to the support for variable load platforms in the HEMTT's conventional power systems. Please make sure this is no an issue for the FTTS-MSV in its demonstrator vehicles.
End State of Concept	FALSE
Issue Related	TRUE
Major Decision Related	FALSE
Milestone Related	FALSE
Requirement Related	TRUE
Resource Related	FALSE
Timeframe Related	FALSE

Table 5.11 Summary of Decision Object Characteristics

A view of the persisted decision object from the CSCW prototype is shown in Figure 5.3.

Figure 5.3 Completed Decision Item within the CSCW Environment

Analysis of Case Study II

The second case study successfully touched all four elements of the framework - utilizing a CSCW environment for managing information, work conducted within a product development process work stream, leveraging decision-oriented information, and making use of risk information. Prototype advisor tools were used to locate information having significance to the simulated decision, and relevant information was captured in a decision-based object.

The information returned from the first simulation runs - similar to items returned in the first case study - suggest inputs to a decision maker who, depending on their experience with the concept, may find relevant. By far, the most interesting aspect of the information returned had to do with the single risk item related to an article from the publication *National Defense* on the apparent problems with the Army's Hybrid vehicles [135]. While the tone of the article is cautionary in regard to hybrid vehicle technologies, it is near the end of the article where some information appeared to be "different" to what has been previously identified or discovered. According to the article – which includes comments from TACOM-based engineers not linked to the Advanced Concepts Team - hybrids where the only platform to fully support a strategy to get load handling systems to the same elevation as the C-130 cargo hold for the HEMTT vehicles. According to the article, a conventional truck has some significant drivetrain components in the center of the truck affecting on the location of lift

equipment. By going with the hybrid approach, the design team was able to embed the load handling system within the profile of the C-130 airplane.

In the role of the decision maker, the information from the simulation may be considered quite significant to the concept since the HEMTT – the most recent "precursor" to the FTTS system – was described to have problems with variable elevation operations of the cargo deck with conventional drive trains. As a decision maker, a next step would be to make sure the information is further investigated and reviewed within the concept development activities. Feedback from the investigation and review should be incorporated into the development of the FTTS-MSV and future concept work.

Analysis of Case Study II with the Advanced Concepts Team

The results of the there simulation runs were reviewed with members of the Advanced Concepts Team (ACT) for further analysis and comment. The team expressed interest in the three sets of information presented by the advisor. The journal article on hybrid technology generated the most discussion, as it was deemed an important reference point. The lead concept engineer on the multi-purpose crane mentioned he was aware of the design issues with adjustable suspensions on the HEMTT, so it is plausible the issue was considered during the concept phase.

OVERALL ANALYSIS

From an overall perspective, the CSCW prototype developed with the principles of the framework performed well with the two test cases. As demonstrated in Case Study II, all elements of the framework were leveraged in the decision making exercise. In support of Tversky et. al [102] as well as Linden's design of Amazon.com recommendation lists [90], the filtered data sets returned to the decision maker from the advisor tools was limited to a select group of results. The feedback from the Advanced Concepts Team on the framework was also positive. Along with the analysis provided on during the review of the two case studies, the team viewed the framework as a possible avenue for planning and deployment for future collaborative systems.

In terms of the data discovery, both case studies demonstrated the affect, as described by O'Dell et. al. as "if we only knew what we know" [13]. In Case Study I, a legacy ammunition study offered insight related to packaging, storage, and removal of munitions magazines. In Case Study II, lessons learned from the application of a variable height material handling deck on a precursor to the FTTS-MSV could have impact on the multi-purpose crane concept. In both situations, the information was not explicitly called out as "FTTS related" or, in the case of the multi-purpose crane, as "material handling equipment" related. Still, the prototype successfully put forward "discovered" information which potentially had a level of significance on the overall concept decision activity. The two discoveries provide validation for the framework by leveraging information for leaders make better decisions.

CHAPTER 6 – CONCLUSION

SUMMARY

Bringing new products to market is a relentless task due never-ending competitive and technological pressures. Even with advances put forth through formalized product development processes, computerized tools, and other technologies, the process of bringing a product from concept to product has not become any less complex. Throughout all product development activities, decision making remains a cornerstone activity affecting every aspect of the process. The challenge of any product development organization is to ensure consistent, timely, and complete information is provided to decision makers to facilitate faster and more accurate decision making.

The premise of this research was to investigate what can be done to optimize development-focused computer tools to allow improvement through reducing levels of uncertainty in concept development decision-making. The result of the research was a four-element framework offering guidance for both implementation and usage of managed data for concept development activities.

The framework itself offers no "quick fixes" – no panaceas for organizations struggling with systems deployed to support product development activities. Further, the framework does not advocate any "miracle" technology to take the place of the decision maker. Rather, through the application and use of the framework principles, organizations can begin to move beyond using

collaborative data management systems to supplement processes. Instead, organizations can harness the power of their information to "move the bar" in reducing uncertainty and positively impact the concept development process.

CONTRIBUTIONS

Identification of a series of steps covering both implementation and usage for optimizing CSCW system benefits for decision makers.

The four core elements of the framework provide a guide covering both implementation ("pre-production") *and* usage ("production"). Additionally, the elements provided in the framework are constructed for directed, practical application.

Introduction of the "Need-Decision-Result" (NDR) relationship for extracting, storing, and reusing decision-related data

Within this framework, decision information has been shown to be a valuable commodity for gleaning useful insight to aid concept product development decision making. The framework advocates capturing key elements of a decision having relevance to future decision makers combined with information supporting both "before" (the needs) and "after" (the results) aspects of the decision.

FURTHER WORK

The introduction of the framework allows a number of opportunities for future work. Because the value of harnessing decisions needs to occur over a relatively long period of time, a long-term study should be commissioned to examine the effectiveness of leveraging the NDR relationship in a concept development environment. A series of checkpoints and measurements should be established to measure how the data set influences concept development team and decision makers over time. Monplaisir [28] demonstrated the use of ANOVA to measure several key indicators within work task processing to determine whether CSCW tools have a statistically significant impact on product development activities.

The decision advisor tools used in the CSCW prototype should be enhanced for production use. The tools should be linked with taxonomy and ontologically-based processing engines to further improve the quality of filtered data items. Further, it is expected that advancements brought forth through the Semantic Web initiative may allow greater enhancement on both the decision advising tools as well as how metadata is captured and managed within CSCW environments.

APPENDIX A – RESEARCH QUESTIONAIRE

Purpose

The survey was to gain further insight in the following areas:

- Identify types of decisions that real organizations make in the concept and design phases of product development.
- Understand the decision that is being made
- The alternatives/choices offered in the decision
- Who the decision-maker(s) are
- What data is directly impacted by the decision
- What other data was used/referenced to make the decision by the decision-maker.
- How often the decision is made (in general) and estimates on which alternative was chosen.
- Reasons why the decision was made in one way or the other.
- Understand what information systems are accessed/referenced by decision makers in order to help them make a decision.

Approach

Respondents involved with product development participated in the survey via written correspondence, live interview, or both. In the section below, questions are provided along with a consolidated set of responses. General responses and the number of observations are provided in parenthesis.

Product Development

Please describe the major purposes, products, or functions of your organization.
OEM automobile producer (4)
OEM automobile supplier (3)
Government or related – direct or contractor (6)
Software (1)
Other (1)

What is your (or your team's) role in relation to product development cycle(s)?
Manager (6)
Engineer/Designer (5)
Consultant (3)
Other (1)

In what ways does your team play a role in some other organization's (internal or external) product development cycle.

Internal (14)
External – Supplier/Contractor to another organization (12)
External – Receiver/Contract Owner for other organizations (12)
No Response (1)

To what degree does your organization share product development data internally (with other groups) and externally?

Share internally (14)
Share externally (12)
No Response (1)

Please describe key elements of the IT structure used by your or to support product development activities.

"Shared network drives"
"CAD"
"PDM systems"

What does the term "product development process" mean to you/your organization?

"Design, engineering, validation to arrive at an end result – customer satisfying product"
"Development of a product"

Does your organization follow a standard or documented product development process (Y/N)?

Yes (9)
No (4)
No response (2)

If yes, please answer the following questions:

Was your PDP developed internally (Y/N)?

Yes (5)
Do not know (4)

Was your PDP based on or influenced by any external source – published methodology, outside consultant, related organization (Y/N)? If yes, can you name the source?

No responses or "No" for all

What are the phases of your organization PDP, in particular the "early" phases?

"Define, establish procedures, train, implement, refine"
"Design, review, prototype"
"Design prototype, testing"

Overall, how "effective" has your PDP been in supporting the goals of the organization?

Very effective

Somewhat effective (4)
No reel effect on the development ectivities (neutrel) (5)
Somewhet ineffective (3)
Very ineffective
No response (3)

Computer Systems

Does your organization use software systems to support PDP and PDP decision-making activities?
      Yes (14)
      No response (1)

If Yes -
Please describe the types of software systems:
      CAD – CATIA, IDEAS, Pro/E, AutoCAD, Unigraphics, CADKEY
      PDM – Windchill, Teemcenter
      Access, Excel
      "Pretty low level stuff" (2)

How "in sync" are your software systems to your organizations PDP processes? Are the systems supportive to how your org. creates products?
      Highly synchronized
      Somewhat synchronized (9)
      Somewhet unsynchronized (3)
      Highly unsynchronized (1)
      No response (2)

      Very herd to find informetion when needed. Too much dete stored ell over.

Are formalized "work flow" based systems used to support your PDP (Y/N)?
      Yes (7)
      No (4)
      No response (4)

If Yes –
How much of your PDP is modeled/embedded in work flow processes (give percentage)?
      90% or more (2)
      50% or more (3)
      No idea (2)

Is work flow processing used as a mechanism to aid in decision-making activities?
      Yes (5)
      No (2)

Can you describe decisions in your PDP where work flows used as a mechanism for decision-making "is a good fit" (for the tool)?
      Sending informetion to menufacturing

Design raviaw
Enginearing changa reviaws

Can you describe decisions in your PDP where work flows used as a mechanism for decision-making are NOT a "good fit" (for the tool)?

No or no response across tha board.

Please describe the use of the Internet and Web-based technologies in your product development activities.

PDM systams ara Wab based, only accassibla via intranet

What types of data is considered a "product" of your product development process? How is it managed?

End parts supplied to customars
Concepts and studies
Raleasad softwara
Data managed in internal and customer systems such as iMan, Metaphase, and VPN

Decision Making, Data, and Integration

At a high level, please describe the types (or examples) of <u>decisions</u> your organization makes to support product development. How are decision typically made – who is involved, what kind of data is used in the decision making, what are the results, and what influences the decisions.

Suggested sheet metal anvironments such as tolarances, radius, construction, and gaps
Whathar to bid on a projact or not
Releasing dasigns to manufacturing

How are decisions "captured" in your organization? What kind of information related to decisions is actually captured *as part of or with the decision* (i.e. what data was used to help make the decision)?

Not aware of any specific capturing procassas
Soma FEA, benchmarking, target values fro customars
Decisions made in workflow processes

Do you think there is value in capturing information that was used to help or influence a decision?

Yas (14)
No response (1)

What types of decisions would this type of information be useful for?
Things gone right, things gone wrong

Cost avoidanca
Timing issuas and delays
Product delivary issues
Cost reductions

How would you rate your organization's ability to capture information supporting a decision (High/Medium/Low)?

Low (8)
Medium (3)
High (2)
No response (2)

Does your organization promote "lessons learned"? If so, how? Do you think it is effective in your organization?
Yes (9)
No (4)
No response (2)

We sey we do, but reelly do not.
Current methods ere progrem reviews
Project notebooks
After Action Reviews

Does your organization reuse information from past decisions in current decision-making activities?
No (10)
Yes (3)
No response (2)

Lessons leemed in project notebooks

Please take a moment to identify a PDP-based decision-making activity that you are familiar with and can describe in detail where the use of past decision history and information could influence.
Understanding the onginel requirements/needs end meking sure es the need edjusts, the decision does es well (mentioned e couple times)
Using FEA end other inputs consistently
Problems with designs
Poorly executed concepts

With the detailed decision in mind, now put yourself in the position of a new manager/engineer who must make this decision. Where would you tell that person to gain knowledge to make a decision?
Understend how requirement chenges impect decisions
Attempt to locete es much similer dete es possible for e decision
Know where to find informetion to meke decisions

What kind of "external" data is used in your organization's product development activities (primarily decision-making related)?
Very little, except in crisis situetions
Acedemic studies

What (or how) does your organization get this external data – is there too much reliance on just what individuals know?
Yes (9)
Systems very unregulated et finding informetion, uneble to seerch
Too much "who you know", not enough knowing where to find data.

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ABSTRACT

A FRAMEWORK FOR IMPLEMENTING A CSCW ENVIRONMENT TO IMPROVE PRODUCT DEVELOPMENT DECISION-MAKING

by

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Advisor: Dr. Leslie Monplaisir

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Despite advances in computer technology, bringing products to market remains a complex activity rife with uncertainty. In particular, it is within the concepting phase of the product development cycle where information used to make decisions is at its most nebulous. Organizations invest resources into collaboratively-oriented computer systems aimed at providing decision makers access to a comprehensive data set, yet may not be experiencing full potential from the environment.

One aspect of the organizational data set used to support concept-oriented decision making is insight gained from past activities, sometimes referred to as "lessons learned". Understanding the impact of a decision becomes valuable as resulting events are derived over time. By leveraging aspects of past decisions linked with original needs and subsequent outcomes, a

compelling narrative can be extracted from the historical data set to benefit decision makers. In practice, most computer data management systems are not equipped by design or in use to efficiently capture elements from past decisions. Therefore, optimizing the technology environment supporting concept development becomes important to promote efforts to reduce uncertainty in decision making. This research provides a framework by which a Computer Supported Cooperative Work (CSCW) environment can be effectively deployed and used to support decision making in the concept development environment. The goal is to provide a concise set of information to end users combining decision-oriented data with relevant artifacts to reduce uncertainty or influence outcomes.

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